REPORT on the GEOLOGIC and GEOMORPHIC CHARACTERISTICS of the MATTOLE RIVER WATERSHED, CALIFORNIA

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REPORT on the GEOLOGIC and GEOMORPHIC CHARACTERISTICS of the MATTOLE RIVER WATERSHED, CALIFORNIA

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EXECUTIVE SUMMARY

This report presents the data and findings of the Department of Conservation, California Geological Survey (CGS) investigation of landsliding and fluvial geomorphology within the Mattole River study area. This investigation was primarily based on interpretation of 1984 and 2000 aerial photographs, and includes findings from CGS's previous watersheds mapping program conducted in the early to mid-1980s. A landslide and geomorphic features map and a landslide potential map are included as Plates 1 and 2, respectively. CGS also created a geographic database for use by landowners, land managers, geologists, and other agencies to identify geologic and geomorphic conditions throughout the study area. This report text describes the methods of investigation used by CGS, and presents our analyses of the important features of, and interrelationships between, the data collected for this study. The report also describes investigation findings pertinent to individual subbasins within the study area, primarily for integration with the synthesis report on the Mattole watershed, prepared by the multi-agency North Coast Watershed Assessment group.

The Mattole watershed processes are dominated by geology and active tectonics. The Mendocino Triple Junction, where the San Andreas fault system transitions into the Cascadia subduction zone, lies in the general vicinity of the lower Mattole River and immediate offshore region. The tectonic activity associated with the triple junction has resulted in extremely high uplift rates, producing the high relief and steep slopes of the King Range and other mountainous areas. This high relief combines with prevailing storm systems to produce exceptionally high rainfall amounts in the Mattole watershed. Several broad shear zones related to the triple junction, characterized by strongly sheared, weak rock, are located primarily in the northern part of the Mattole watershed. The combination of weak geologic materials, steep slopes, high rainfall, and common strong earthquakes results in high rates of natural landsliding and surface erosion, particularly in the northern portion of the study area.

The distribution and mode of movement of landslides are both strongly related to bedrock geology. For purposes of analysis, the bedrock geomorphic units mapped by McLaughlin and others (2000) were combined into three categories (hard, moderate, and soft terrains). The one-quarter of the watershed identified as underlain by the soft terrain is highly susceptible to natural landsliding, and contains the majority of recognized gullies. Almost 50% of the area occupied by recognized landslides lies within this geologic material. Most of this soft terrain is found in the northern subbasin, while the southern subbasin is underlain by hard terrain, which contains the least mapped landslides. Large earthflows and complex rockslides dominate the slope failures in the soft terrain, while debris slides are the most common mode of failure in the hard terrain. The hard and moderate terrains support steeper slopes, while the slope distribution in the soft terrain is shifted toward gentler slopes.

Most of the small (<100 feet diameter) landslides were located in the hard and, to a lesser degree, moderate terrain. Inner gorges have formed along approximately 42% of bedrock blue-line streams, often extending beyond the end of the blue-line stream, and have preferentially formed in the hard terrain throughout the study area. Overall, considering both large and small landslides, approximately ¾ of all historically-active landslides were interpreted to have delivered sediment to streams.

A landslide potential map was derived from the geologic, landslide, and geomorphic data, as well as the hillside gradients. This map depicts the regions thought by CGS geologists to represent the most likely sources of sediment in the future. Over half of the study area is interpreted to have high to very high landslide potential, which is considered to be reasonable in this geologically-active region. The prevalence of soft terrain and steep to very steep slopes in various portions of the watershed are the main contributors to those classifications. The Northern and Coastal subbasins have the largest proportion of high to very high landslide potential, while the Southern subbasin has the lowest.

Fluvial-geomorphic mapping of channel characteristics that may indicate excess sediment accumulations suggest that channel conditions across the watershed have generally improved between 1984 and 2000. The percentage of blue-line streams occupied by negative mapped channel characteristics (NMCCs) decreased during this time interval, with the Eastern subbasin showing the highest percentage improvement and the Northern subbasin the lowest. The greatest improvement (reduction) in NMCCs was in reaches where displaced riparian vegetation was the primary mapped feature. Little improvement, however, was noted in channel conditions for streams lying within Quaternary deposits, which are predominantly found along the lower reaches of the Mattole stream network.

Finally, our analyses of NMCCs in streams adjacent to high and very high landslide potential indicate that virtually all mapped channel characteristics in bedrock terrains were located in areas designated as having high or very high landslide potential. These findings suggest that the landslide potential map (Plate 2) can also be used to identify the most likely locations to find impacts resulting from excess sediment in the bedrock stream reaches. However, additional research may be needed to determine what specific portions of the high and very high landslide potential areas are associated with the negative mapped stream characteristics.

INTRODUCTION

The multi-agency North Coast Watersheds Assessment Program (NCWAP) was designed to provide a scientific foundation for collaborative watershed restoration efforts and to better meet the State needs for protecting and restoring salmon species and their habitats under state and federal laws. The Department of Conservation/California Geological Survey (CGS) is partnering with other agencies in the assessment effort, under the guidance of the California Resources Agency. These California agencies include the Department of Fish & Game, Department of Forestry, Fire and Resource Assessment Program, Department of Water Resources and North Coast Regional Water Quality control Board. Information collected as part of the NCWAP assessment process should assist landowners, government agencies, and local watershed groups in their understanding of watershed processes, and also aid in the development of watershed-restoration projects, determination of values for Total Maximum Daily Loads for sediment, watershed-management strategies, and watershed plans.

Purpose

This report is an Appendix to the NCWAP Mattole Watershed Synthesis report, and is intended to also stand alone as a geologic report of the Mattole study area. CGS's role in the NCWAP is to update existing landslide maps, provide new landslide maps where needed, and provide fluvial (i.e., stream channel) geomorphic maps for selected North Coast watersheds. Our effort is geared toward providing regional baseline geologic data for use in land-use planning and restoration activities by other entities. Maps, figures, tables and text prepared for this study are intended to provide a starting point for scientifically-based watershed assessment, and should therefore not be used as a substitute for site-specific studies.

Understanding the geology, relative slope stability and fluvial-geomorphic characteristics within the Mattole region is critical in the assessment of current watershed conditions, the relative impact of past land-use practices, and development of mitigation measures to improve aquatic habitat conditions. The bedrock beneath the Mattole watershed has in many places been tectonically broken and sheared, making it weak, easily weathered, and inherently susceptible to landsliding and erosion. Unstable bedrock and soil conditions, combined with high relief, steep slopes, heavy rainfall, and rapid regional uplift rates, have produced widespread landsliding, which has resulted in large volumes of sediment input to streams. The naturally-occurring conditions that contribute to slope instability have undoubtedly been exacerbated by detrimental human activities at places within the watershed. Past land-use practices associated with road construction, timber harvest, grazing, man-induced burning, and subdivision construction have likely contributed to the reactivation of preexisting dormant landslides, creation of new landslides, and directly contributed sediment to streams.

The regional-scale landslide mapping and assessment of background geologic conditions that have been performed for this study provide a framework for understanding the sensitivity of an area to slope instability and human disturbance. However, it is presently unknown (and beyond CGS's scope to quantitatively assess) to what degree land use has accelerated natural mass wasting and erosion levels in the watershed, and how long the residual effects may last. The enclosed findings can, however, provide a starting point for future long-term studies that may be undertaken to evaluate trends toward "recovery" in watershed conditions.

Physiography and Climate

The Mattole study area (Figure 1) is located just south of Cape Mendocino in the Coast Ranges geomorphic province of California (Norris and Webb, 1976). Paved county roads provide public access into the watershed from the north through Ferndale, and from the east off Highway 101 near Garberville or through Humboldt Redwoods State Park. The Mattole River basin encompasses approximately 296 square miles, and the adjacent coastal basins within the study area an additional 76 square miles. Topographically, the study area may generally be described as steep and mountainous with narrow canyon bottoms, although relatively broad valleys and flat-lying stream terraces exist locally along the mainstem and larger tributaries of the Mattole River. Elevations vary from sea level along the coast to 4,088 feet on Kings Peak, which is located less than three miles inland. The Mattole River is approximately 62 miles long and receives water from over 74 tributary streams. The southernmost headwaters of the Mattole River originate in Mendocino County, but the great majority of the river basin is within Humboldt County.

The area has a Mediterranean climate generally characterized by cool wet winters with high runoff, and dry warm summers with greatly reduced flows. Due to the influence of the Pacific Ocean and the orographic effects of the King Range, there are significant variations in temperature and precipitation across the watershed. Average temperatures along the coast range between approximately 46 and 56 degrees Fahrenheit. Farther inland, temperatures are much more varied, ranging from below freezing in winter to over 100 degrees in summer. Most precipitation occurs as rain during the winter months, with portions of the watershed receiving some of the highest annual rainfall totals in California. Based on precipitation gauge data compiled by the Department of Water Resources, average rainfall measured near the coast at Petrolia is around 60 inches per year, while near the middle of the watershed at Honeydew it averages over 100 inches per year. Occasionally the watershed is impacted by extreme rain seasons and events, such as in 1982-1983 when over 240 inches fell over some areas, and in 1956 when 13.65 inches fell on Honeydew in a single 24-hour period. Precipitation also occurs as snow at higher elevations in the watershed, with subsequent and destructive rain on snow events impacting the area, such as reportedly occurred in December 1964. During winter months, stream flows in the Mattole River average between approximately 1,710 and 4,170 cubic feet per second (cfs), measured at a United States Geological Survey (USGS) gauging station near Petrolia. During the summer, flows commonly drop below 60 cfs, and have been measured as low as 20 cfs. The highest recorded peak flood events along the Mattole River were in December 1955, when maximum discharge reached 90,400 cfs, and in December 1964, when it reached 78,500 cfs.

Report Overview

The following sections provide a brief background of the regional geologic and tectonic setting of the Mattole study area, including a general discussion on faulting, seismicity and uplift rates. Geologic units present within the watershed are described, along with background information on landslide types, processes and general stream geomorphic characteristics. After an overview of CGS's investigation methods, our findings regarding landslides, relative slope stability and fluvial geomorphology are presented. The report concludes with a brief recap of the most important findings and conclusions developed from our analysis.

Appendix 1 lists the terms and acronyms used throughout this report for easy reference. Appendix 2 presents a glossary of landslide-related terms while Appendix 3 is a photographic dictionary of the types of fluvial features mapped for this study. Watershed-scale maps (1:24,000) that accompany this report illustrate the spatial distribution of geologic units, landslides, and related geomorphic features (Plate 1), as well as relative landslide potential (Plate 2).

CGS's mapped area includes the Mattole River watershed, investigated by the entire NCWAP team, as well as the coastal drainages to the west of the Mattole basin. The larger area is referred to herein as the Mattole study area. The Calwater 2.2a planning watersheds, as well as the subbasins used in the Mattole Synthesis Report, are shown in Figure 2.

The California Division of Mines and Geology (DMG) was renamed California Geological Survey (CGS) in January 2002. These names are used interchangeably in this text.

TECTONIC AND GEOLOGIC SETTING

The Mattole study area is situated in the geologically complex and tectonically-active area of the Mendocino Triple Junction where the North American, Pacific, and Gorda crustal plates meet (Figure 3). North of the triple junction, the Gorda plate is subducting beneath North America along the Cascadia subduction zone, while south of the triple junction, the Pacific plate meets North America along the San Andreas fault system. Offshore, the Pacific and Gorda plates meet along the strike-slip Mendocino fracture. Due to the relative motions of the three plates, the Mendocino Triple Junction has been migrating northward at an estimated rate of 48 mm/yr (Furlong, 1991; Merritts and Vincent, 1989). Immediately south of the triple junction, subduction has only recently ceased, and the strike-slip San Andreas fault system is still becoming established. The actual configuration of the plate boundaries and related fault systems is complex, with the location of the triple junction currently placed within a poorly-defined region that incorporates the lower Mattole basin and the adjacent offshore area. Because of its proximity to the triple junction, the Mattole watershed experiences some of the highest rates of crustal deformation, surface uplift, and seismic activity in North America (Merritts, 1996).

As may be expected in this tectonically-complex region, the geology of the study area is also multifaceted. During past subduction, some oceanic material was scraped off the down-going slab and accreted to the western edge of the North American plate. Rock material thus added to the continent, named the Franciscan Complex in coastal California, consists primarily of marine sandstone and shale, with blocks of limestone, basalt and serpentinite. The rocks of the Franciscan Complex are typically metamorphosed to variable degrees, and can be highly disrupted, with zones of strongly sheared shale matrix containing relatively intact blocks of diverse rock types and sizes. This tectonic mélange is highly variable in its physical characteristics and susceptibility to landsliding, depending in large part on the relative amounts of sheared and intact rock.

The basement rocks of the Mattole study area are assigned to the Coastal belt and Central belt of the Franciscan Complex (Irwin, 1960; McLaughlin and others, 2000, Figure 4). The currently-accepted geologic model indicates that the bulk of the geologic units were deposited along a trench/slope margin and subsequently accreted to the North American plate margin. The sedimentary rocks are locally mixed with scrapings off the oceanic Gorda Plate and other exotic blocks of obducted material (McLaughlin and others, 1982, 1983, 1994). The structurally-disrupted belts of the Franciscan Complex generally become younger and less metamorphosed from east to west. Late Cenozoic marine and nonmarine deposits assigned to the Wildcat Group underlie a limited area in the northwestern portion of the study area. These deposits have been juxtaposed with the structurally-underlying Franciscan Complex by Pliocene to Pleistocene thrust faulting (McLaughlin and others, 2000). Overlying the bedrock units are varieties of unconsolidated Quaternary sedimentary units including alluvial fans, river and marine terrace deposits, and alluvium. The geologic units exposed in the Mattole study area are described in more detail below.

Faulting and Seismicity

The major fault structures within the Mattole study area are the Cooskie and Petrolia shear zones, and the San Andreas Fault (Figure 3). The Cooskie shear zone, a poorly-defined zone of sheared and broken rock, extends easterly from Punta Gorda. The Petrolia shear zone is a similar structure, extending southeast through Petrolia toward Honeydew along the Mattole River. If the Cooskie and Petrolia shear zones are on-land extensions of the offshore plate boundary fault systems (the Mendocino fracture and the Cascadia subduction zone, respectively), they may represent significant, potentially-active fault zones (McPherson and Dengler, 1992; Clarke and McLaughlin, 1992).

The San Andreas fault is generally defined as the boundary between the North American and Pacific plates. Within the study area, surface rupture associated with the 1906 earthquake probably propagated from Shelter Cove approximately 3 km northward (Brown, 1995; Prentice and others, 1999), which by definition would indicate that this trace belongs to the San Andreas fault. However, this may be a secondary fault, and the definition of the plate boundary remains controversial. Some investigators (e.g., Jachens and Griscom, 1994; Curray and Nason, 1967) place the primary fault structure immediately offshore. Others (Clarke and McLaughlin, 1992) place the San Andreas fault as far east as the poorly-characterized Mattole shear zone, which appears to be the same structure as the King Range Thrust fault (Figure 3). The effective plate boundary in this vicinity is likely to be broad and indistinct, as it is a relatively new tectonic feature, and therefore not well developed. CGS has designated that portion of the fault structure extending northwards from Shelter Cove to the vicinity of Kaluna Cliffs as active (Hart, 1996). Extensive landsliding and a non-definitive geomorphic expression prevented CGS from defining the active fault farther north. Interested parties should consult the *Earthquake Fault Zone Map* (DMG, 1998) and the *Fault Evaluation Report* (Hart, 1996) for location of the officially-defined active fault zone.

Major historical earthquakes in the region have occurred in intraplate zones as well as along well-defined faults (Dengler and others, 1992; Oppenheimer and others, 1993). For example, the rapid uplift described below is being accommodated along a system of thrust faults, some of which may not extend upward to the ground surface (McLaughlin and others, 2000; Figure 5). The Honeydew earthquake (August 1991, M 6.2) occurred on one of these faults, when the southwest block was thrust upward over the northeast block at depth. Although the earthquake reactivated landslides and resulted in a zone of ground cracking, the rupture surface along the fault plane did not extend to the ground surface (McPherson and Dengler, 1992). Similarly, the main shock of the Cape Mendocino earthquake (April 1992, M 7.1) centered near Petrolia occurred on a low-angle thrust fault near the base of the North American plate that caused significant ground shaking and coastal uplift, but did not produce surface rupture (Oppenheimer and others, 1993). The two largest aftershocks to the Cape

Mendocino earthquake apparently occurred within the Gorda plate offshore and were both M 6.6 events (Oppenheimer and others, 1993).

The Mattole region experiences a high level of seismic activity, with common earthquakes large enough to damage structures, as well as occasional extreme events of magnitude 8.5 or greater (Dengler and others, 1992). At least 60 damaging earthquakes have occurred near the coastal portion of Humboldt County since the mid 1800's (Dengler and others, 1992). A particularly active zone of historical seismicity is found in the Punta Gorda/Cape Mendocino vicinity (Figure 3; Dengler and others, 1992; Oppenheimer and others, 1993). Major earthquakes often activate landslides, so the high rate of seismicity in the Mattole region probably contributes to a high natural rate of landsliding.

Quaternary Uplift

High rates of regional uplift provide a regenerating source of sediment to the watershed. Studies of marine and fluvial terraces (McLaughlin and others, 1983; Merritts and Bull, 1989; Merritts, 1996) indicate that tectonic uplift rates range from 1 mm/yr (near Shelter Cove) to 4 mm/yr (near Shipman Creek, 10 miles to the north; Figure 2) during the past 120,000 years. Wave-cut Holocene platforms along the coast have been elevated more than 50 feet above a rising postglacial sea level, which shows that the rapid uplift has continued through the Holocene (Merritts, 1996). Fission track data (Dumitru, 1991) supports this range of uplift rates during the past 1.2 million years, and postulates that a major, vertical-motion fault is required between these two locations to accommodate this dramatic difference in uplift rates, although none has been recognized. Elevated alluvial and strath terraces along the Mattole River indicate that relatively high rates of uplift persist inland beyond the easterly boundary of the watershed (Merritts, 1996), and a study of fluvial terraces along the Eel River south of Garberville supports extension of the high uplift rates toward the east (Bickner, 1992).

This uplift is thought to be in part due to a broad regional warping related to northeast-southwest-oriented compression along the North American and Pacific plate boundary. Active thrust faulting along the north and east sides of the King Range and movement along relatively flat, blind thrusts associated with the southern Cascadia subduction zone probably contribute to the uplift as well (Figure 5; McLaughlin and others, 2000). Following the 1992 Cape Mendocino earthquake, Carver and others (1994) documented coastal emergence, which indicated up to roughly 1.4 m of coseismic uplift between Cape Mendocino and the south side of Punta Gorda. The coastal uplift caused by the 1992 Cape Mendocino quake is the largest in the coterminous United States during any historic earthquake (Carver and others, 1994), although it does not appear to be an uncommon event relative to the Quaternary evolution of the Mattole region.

Long Term Stream Aggradation and Incision

Due to glacial melting, global sea level has risen approximately 120 m over the past 18,000 years (Fairbanks, 1989). In general terms, global sea level rose most rapidly between 13,000 and 9,000 years ago, and has risen more slowly in recent times. In coastal stream basins worldwide, this rise in base level has resulted in drowned river mouths, the development of estuaries, and stream aggradation in the lower reaches.

The effects of sea level rise on the Mattole River have been described by Merritts and others (1992; 1994). From the initiation of sea level rise at 18,000 years before present (BP) to approximately 6,500 years BP, sea level was rising faster than the land surface near the mouth of the Mattole River. During this time, global sea level rose an average of 9.4 mm/yr (Fairbanks, 1989). Assuming a constant land surface uplift rate of 2.6 mm/yr near the mouth of the Mattole (Merritts and others, 1994), the net effect was to drown the coastline and river mouth by approximately 78 m during this time. The backwater effect associated with this rise in base level resulted in extensive sediment deposition and stream aggradation along the lower Mattole River as well as the lower tributary streams. The sediment forms a wedge, thickening seaward where the late Pleistocene stream channel was lowest.

The upstream limit of this sediment wedge lies in the general vicinity of where the Mattole River crosses the quadrangle boundary between Shubrick Peak and Buckeye Mountain (Plate 1). Upstream of this point, the stream overlies bedrock with a thin, mobile mantle of alluvium, and the stream channel gradient is approximately 0.32%. Downstream of this point, the stream overlies stored alluvial sediment, and the stream gradient flattens to approximately 0.14%. A U.S. Geological Survey borehole located 5 km upstream of the river mouth encountered possible bedrock at a depth of 37 m (-23 m elevation) (Merritts and others, 1994). If this bedrock surface is projected upstream to the upper limit of the alluvial wedge, then the buried bedrock channel in the lower Mattole basin has a similar gradient (0.32%) to the active bedrock channel upstream of the alluvial wedge.

Over the past 6,500 years, the rate of sea level rise has dropped below the rate of ground surface uplift, resulting in a relative base level drop, increased stream gradient, and associated stream incision. The Mattole River has incised approximately 7 to 10 m near the mouth, and 5 to 7 m near the upstream end of the sediment wedge (Merritts and others, 1994).

Geologic Units

The Mattole study area is underlain by the Central belt and Coastal belt of the Franciscan Complex. The Coastal belt has been further divided into three tectonostratigraphic terranes that generally become younger in age toward the west, although there is some overlap in age. These terranes are separated by broadly northwest-trending shear zones. Progressing from northeast to southwest are the Yager, Coastal, and King Range terranes (McLaughlin and others, 2000; Figure 4). These units consist dominantly of fine-grained clayey rock (argillite) and sandstone that have been pervasively folded, sheared, and otherwise variably disrupted by tectonic processes.

Through photointerpretive mapping, McLaughlin and others (2000) further subdivided the Central belt and each terrane within the Coastal belt into three or four subunits, which form the geologic map units depicted on Plate 1. These subunits were delineated by systematic mapping of topographic expression as viewed in high-altitude stereo photography, combined with reconnaissance field observations of lithology and structural condition of the rock (Ellen and Wentworth, 1995). For example, hard topography (subunits y3, co4, and krk3 on Plate 1), which consists of sharp-crested ridges with steep slopes and well-incised drainages, tends to develop where sandstone dominates, the rock mass is relatively intact, and clayey sheared rock is largely absent. In contrast, soft topography (subunits cm1 and co1), which consists of rounded crests with gentle slopes and poorly developed sidehill drainages, generally is underlain by pervasively sheared clay-rich mélange. Additional subunits of McLaughlin and others (2000) show topographic characteristics between these two end members. These subunits show a good correlation with the different types of mass wasting processes that occur in the study area, as discussed in "Investigation Findings."

<u>Central Belt Franciscan</u>

Late Jurassic to Paleocene(?)-age rocks of the Franciscan Central belt are confined to a relatively small area along the eastern edge of the Mattole watershed in the Ettersburg quadrangle. This unit is a tectonic mélange composed of exotic blocks of diverse lithologies and ages, ranging from outcrop size to more than a mile across, in a matrix of penetratively sheared argillite (subunit cm1 on Plate 1). Blocks within the matrix include chert, serpentinite, greenstone, and structurally more intact blocks of metamorphosed sandstone, argillite and conglomerate.

<u>Coastal Belt Franciscan, Yager Terrane</u>

Paleocene (?) to Eocene-age rocks of the Yager terrane underlie the eastern portion of the watershed from near Briceland on the south, to northeast of Honeydew in the Bull Creek quadrangle (Plate 1). This unit is composed of predominantly thin-bedded argillite with rhythmically interbedded sandstone and thickly-bedded sandstone channels (subunits y1, y2, and y3 on Plate 1). Minor lenses of polymict boulder to pebble conglomerate (subunit Yclg on Plate 1) are also present. The unit is distinguished from the adjacent Central belt and

Coastal terrane by its lack of exotic blocks within the argillite. Strata are highly folded, but generally less sheared and broken than adjacent units.

Coastal Belt Franciscan, Coastal Terrane

Late Cretaceous to Pliocene-age rocks of the Coastal terrane underlie the majority of the watershed. This unit consists predominantly of sandstone, argillite, and minor polymict conglomerate that is highly folded and variably sheared and broken. Portions of the unit are a penetratively-sheared mélange (subunit co1 on Plate 1) that includes exotic blocks of basalt flows, flow breccias and intrusive rock. Rare blocks of limestone and glaucophane schist are also found in the mélange and along the contact with the King Range terrane, respectively. The mélange is more prevalent in the northern portion of the study area; the less structurally-disrupted subunits (co2, co3 and co4, with co4 being the least disrupted unit) underlie the southern portion of the study area and form some large blocks in the northern portion.

Coastal Belt Franciscan, King Range Terrane

The Late Cretaceous to Miocene-age rocks of the King Range terrane underlie a broad belt along the coast that extends from Whale Gulch on the south to near Punta Gorda on the north (Figure 4). This unit is further divided into the Point Delgada and King Peak subterranes based on structural discontinuity, contrasting lithology, and age differences of the rocks (McLaughlin and others, 1982). The Point Delgada subterrane (Krp on Plate 1) is composed chiefly of pillow basalt, flow breccias and tuffs, and is only exposed in the coastal bluffs and intertidal areas near Shelter Cove. The King Peak subterrane (subunits krk1, krk2, and krk3 on Plate 1) is composed dominantly of sandstone and argillite, with rare blocks of pelagic limestone, chert, basalt, and blueschist. Although lithologically similar to the Coastal terrane, the rocks of the King Peak subterrane are, in general, more structurally intact. The King Range terrane is the most recently accreted rock in the Franciscan Complex (McLaughlin and others, 2000).

Overlap Deposits

Several fault-bounded slivers of post-accretionary sedimentary rock have been recognized in the northwest portion of the watershed near Petrolia. Called “overlap deposits” by McLaughlin and others (2000), these late Cenozoic rocks appear equivalent to parts of the Wildcat Group. The overlap rocks (map unit QTw on Plate 1) are dominantly marine in origin, and consist of weakly to moderately-well lithified sandstone, siltstone, mudstone and minor conglomerate. Quaternary thrust faulting juxtaposed and imbricated the overlap rocks with the accretionary rocks of the Franciscan Coastal terrane (McLaughlin and others, 2000). In contrast to the structurally-underlying accretionary rocks, the overlap rocks are unmetamorphosed, less lithified, and considerably less deformed.

Quaternary Units

Unconsolidated Quaternary deposits overlie the bedrock units, particularly along the lower Mattole River. Fluvial and marine deposits are included in the geologic base map and defined below. Landslide deposits mapped for this program, which may also be considered Quaternary deposits, are described briefly in the following section and in more detail in Appendix 2. Quaternary units are mapped primarily based on geomorphic relationships, as well as sediment description. Units mapped in the Mattole watershed and depicted on Plate 1 include:

- Qmt – Marine Terrace Deposits (Pleistocene-Holocene): Terrace deposits formed in a shallow marine setting on wave-cut benches. Typically consist of well-sorted, clast-supported sands and/or gravels. The degree of consolidation, amount of soil profile development, and elevation of the unit above sea level typically increase with age of the deposit.
- Qrt – River Terraces (Pleistocene – Holocene): Flat-lying to gently-inclined platforms typically overlain by alluvial deposits. Elevated above flood level stage, not likely to be inundated in major storm events. Typically contain some degree of soil profile development.
- Qt – Terrace Deposits, undifferentiated (Pleistocene – Holocene): Alluvial and/or shallow marine deposits of uncertain genesis. Preserved as isolated remnants of older platforms well above present stream level.
- Qoal – Older Alluvium (Pleistocene – Early Holocene): Older alluvial deposits commonly forming terraces above and outside the 100-year flood plain. Vegetation is characteristically well established.
- Qc – Colluvium (Pleistocene – Holocene): Unconsolidated surficial slope deposits, including colluvium, talus, and slope wash.
- Qf – Alluvial Fans (Holocene): Characteristic fan-cone shapes at the mouths of eroding stream canyons. Includes debris fans. Typically consist of subangular rock fragments supported in a finer-grained matrix.
- Qal – Alluvium (Holocene): Undifferentiated alluvial deposits, typically consisting of sands, gravels, silts and clay. May include colluvial, fan, terrace and/or active channel deposits that could not be readily differentiated at the scale of mapping.
- Qbs – Beach Sand (Holocene): Marine-laid deposits of well-sorted fine to coarse-grained sands and gravels. May migrate seasonally.
- Qds – Dune Sands (Holocene): Unconsolidated, subaerially-deposited material adjacent to the coast. Typically consists of well-sorted fine sands. Bare to grassy vegetation, often dependent on distance from coastline.
- Qscu – Active Stream Channel (Holocene): Undifferentiated unconsolidated channel deposits, typically in flood plains likely to be inundated by major storm events.

Landslide Type, Associated Geomorphic Features and Activity

The terminology used in this document and the accompanying map (Plate 1) to describe landslide types and geomorphic features related to landsliding was updated from DMG Note 50. The terminology and language is derived from the previous Watersheds Mapping program conducted by DMG in the early 1980's. Several quadrangles within the Mattole watershed were mapped during that program. Our nomenclature is consistent with that presented in Cruden and Varnes (1996), and our mapping protocols and assessment of activity follows that proposed by Keaton and DeGraff (1996).

Landslide Types

Rockslides were referred to in previous CGS publications as translational/rotational landslides. This slide type is characterized by a somewhat cohesive slide mass and a failure plane that is relatively deep-seated when compared to that of a debris slide of similar areal extent. The sense of the motion is linear in the case of a translational slide, and is arcuate or "rotational" in the case of the rotational slide (i.e., slump). Complex versions involving rotational heads with translation or earthflow downslope are common.

An *earthflow* results from slow to rapid flowage of saturated rock, soil and debris in a semi-viscous, highly-plastic state. Typically composed of clay-rich materials that swell and lose much of their already-low shear strength when wet, slide materials erode easily, resulting in gullying and irregular drainage patterns. The irregular, hummocky ground characteristic of earthflows is generally free of conifers; grasslands and meadows predominate. Failures commonly occur on slopes that are gentle to moderate, although they may also occur on steeper slopes where vegetation has been removed.

A *debris slide* is characterized by weathered and fractured rock, colluvium, and soil that move downslope along a relatively shallow translational failure plane. Debris slides form steep, unvegetated scars in the head region and irregular, hummocky deposits (when present) in the toe region. Debris slide scars are likely to ravel and remain unvegetated for many years. Revegetated scars can be recognized by the even-faceted nature of the slope, steepness of the slope, and the lightbulb-shaped form left by many mid- and upper-slope failures.

Tracks for *debris flows and debris torrents* consist of long stretches of bare, potentially unstable stream channel banks that have been scoured and eroded by the extremely rapid movement of water-laden debris. The tracks commonly result from debris sliding or the failure of fill materials along stream crossings in the upper part of a drainage during high intensity storms. When momentum is lost, scoured debris may be deposited as a tangled mass of large organic debris in a matrix of sediment and finer organic material.

Geomorphic Features

Disrupted ground typically has a hummocky ground surface caused by multiple landslides, possibly of different types of movement, resulting in individual features too numerous and/or too small to delineate at map scale. Earthflows, slumps, and gully erosion may be common within the failure mass, while inner gorges may develop along the lower portions of the slope adjacent to watercourses. This classification is occasionally applied to disturbed ground surface that cannot be positively attributed to specific landslide types or processes, and may include areas affected by downslope creep, differential erosion, and/or expansive soils. Boundaries are typically indistinct, and activity levels may vary throughout the slope. These features are most often mapped in clay-rich, mélange bedrock units.

Gullies are erosional channels produced by running water in earth or unconsolidated material. The channels usually carry water only during and immediately after heavy rains. They generally have steep sides and near-vertical headcuts, which are generally unvegetated. Gullies typically increase in size by surface flow concentrated near the gully's head, and by subsurface flow undercutting the head scarp or the gully walls.

Debris slide slopes and amphitheaters are geomorphic features in which slopes have been sculpted by numerous debris-slide events. Although the slopes often are smooth, steep (often greater than 65 percent), and unbroken by benches, they are characteristically dissected by incipient drainage depressions. In many places, channels within the amphitheaters and slopes are deeply incised with steep walls of rock or colluvial debris.

An *inner gorge* is a geomorphic feature formed by coalescing scars originating from landsliding and erosional processes caused by active stream erosion. This feature is identified as that area of stream bank situated immediately adjacent to the stream channel with a slope of generally over 65 percent, situated below the first break in slope above the stream channel. Inner gorges are typically formed by debris slide processes activated by the downcutting of stream channel bottoms and/or lateral erosion of banks (i.e. at the outsides of bends in the stream). They commonly form along or across from toes of large landslide deposits that are impinging on the stream.

Landslide Activity

In addition to the type of landslide, the recency of movement can be assessed using the freshness of features, as outlined in Keaton and DeGraff (1996), with a slight modification to accommodate the lack of man-made structures in much of the study area. Landslide activity was noted because those landslides that have moved recently are considered more likely to remobilize in the future. For the NCWAP program, recognized landslides are characterized as either historically-active or dormant, and dormant slides are further subdivided based on Keaton and DeGraff's (1996) freshness criteria. Activity criteria were not applied to geomorphic features (debris slide slopes, inner gorges and disrupted ground).

Historically-active slides include those believed to have moved within the last 100 to 150 years, based primarily on observations from the aerial photographs. Historically-active rock slides and earthflows typically have crisp or sharp scarps and lateral flanks, the internal portions of the slide have undrained, hummocky topography, vegetation is typically absent on the lateral and main scarps, and toes are clearly present and well-defined, often pushing out into streams or alluvial flats. Debris slides and debris flow/torrent tracks are considered historically active when recognizable, as are gullies.

Dormant slides are categorized as young, mature or old. Landslide-related features are still clearly recognizable in dormant-young slides, but some features may appear to have been softened by stream and/or weathering activities. Drainages are just becoming established along the lateral margins of the slide mass. Dormant-mature landslide features are typically recognizable, but have been "smoothed over" significantly, with drainages being incised into the body of the slide. Dormant-old landslides have been extensively modified by stream and/or weathering activities, often are heavily dissected internally, and occasionally other geologic features, such as terraces, can be observed within the slide area.

INVESTIGATION METHODOLOGIES

Methods used to compile geologic, landslide and fluvial-geomorphic data are described in more detail in the appendix of the *Draft NCWAP Methods Manual* (April 6, 2001), but are mentioned herein for completeness and clarity. Tasks conducted during this assessment include:

- literature review
- photointerpretation of 2000 and 1984 aerial photographs
- limited site reconnaissance
- incorporating landslide and geomorphic data from previous CGS mapping using 1981 aerial photographs
- entering (digitizing) the data into the ArcView Geographic Information System (GIS) database
- converting the compiled information into ArcInfo
- deriving the landslide-potential map
- preparing two plates showing landslide occurrence and potential to accompany this report
- data analysis using the GIS database
- report preparation

A geologic base map, landslide-inventory map (Plate 1), and landslide-potential map (Plate 2) were all developed as basic data for the project, designed to be used by others as either hard copy (1:24,000 scale), or within the GIS. Fluvial-geomorphic features were compiled into the GIS database. Additional figures and tables presenting results of our analyses of interrelationships within the basic data are included within this report. USGS 7.5' digital topographic maps, digital orthophotoquads, and digital elevation models (DEMs) were used for data analysis.

In addition to the map products presented with this report, the GIS database is available as ArcInfo coverages through both NCWAP and CGS. Separate GIS layers were created for the geologic, landslide-related and fluvial-geomorphic assessments. An individual GIS layer contains one of any number of mapped features, such as dormant landslides, gullies, or geologic units. Because these layers contain the spatial location of the mapped features, they can be digitally "stacked" on top of each other to display data and explore relationships between different types of features. Each feature recorded in the landslide and fluvial layers was assigned numerous attributes, such as type, age, and depth, based on a pre-established method of assessment. The GIS allows us to also explore interrelationships between the various attributes within or across the various layers. Data organization and attributes are shown in Table 1.

Topographic Base Map and DEM

Digital versions of the USGS 7.5-minute quadrangle maps within the study area were obtained from the USGS. These quadrangles were then sutured together electronically to create a digital topographic base map for the study area. A digital elevation model (DEM) derived from this same digital topography data was provided to CGS by our NCWAP agency partner, FRAP. The DEM data files consist of grid cells whose values are interpolated from nearby contour lines. These digital cells can then be used to construct other derivative layers, such as slope ranges and aspect, and were instrumental in the development of our landslide-potential map (Plate 2). The size of the cells used in the DEM is dependent on availability from the USGS; smaller size is considered to give better representation of ground conditions, due to the greater resolution of the smaller cells. The cell size used for this project is 10m by 10m (aka 10m DEM). We also used digital orthophoto quadrangle (DOQ) images obtained from USGS as a backdrop during our digitization process for ease of transfer and enhanced accuracy.

Geologic Base Map

The geologic base map (Plate 1) for the Mattole watershed was compiled from a digital version of a previously published map, interpretation of aerial photographs, and limited field checking where access was available. The map shows the spatial distribution of major geologic units and geologic structures, and describes the general rock types.

Most of the bedrock geology, including mapped units, faults, and other structural elements, was modified from digital version 1.0 of the 1:100,000-scale geologic map MF-2336 (McLaughlin and others, 2000) published by the USGS. This map covers that portion of the watershed within Humboldt County, and may be downloaded as GIS files in ArcInfo export format through the USGS website. The MF-2336 geologic map was developed using photointerpretation of topographic form to subdivide major geologic units into subunits that reflect variations in the lithology and structural condition of the rock (e.g., “topographic hardness”). Photointerpretive mapping of black-and-white aerial photos (WAC, 2000) was performed by CGS staff to extrapolate bedrock map units and structural elements from the MF-2336 map to cover the southernmost portion of the watershed, located within Mendocino County. It is important to note that although the bedrock geology of MF-2336 has been presented herein at a scale of 1:24,000, the detail and accuracy of the data is limited to the spatial resolution of 1:100,000 scale in which the digital database was originally compiled by the USGS.

Mapped landslide deposits, alluvium, and terrace deposits included in the USGS MF-2336 geospatial database were replaced by more detailed mapping of landslides and Quaternary units performed for this and previous CGS studies. Quaternary units were initially mapped at a scale of 1:24,000 from black-and-white aerial photographs (WAC, 2000) and were supplemented with mapping of Quaternary units from earlier work covering portions of the watershed, which was available in digital format (Spittler, 1983a, 1983b, 1984a, 1984b, 1984c, 1984d; CDMG, 1999). Finally, active stream-channel features delineated during this study as part of the fluvial-geomorphic assessment replaced earlier mapping of alluvium. The geologic map was produced in accordance with the conventions and nomenclature established by CGS’s Regional Geologic and Hazards Mapping Programs.

GIS Database

In addition to the map products presented with this report, the GIS database is available as ArcInfo and ArcView through both NCWAP and CGS. One of the goals of the NCWAP program is to facilitate the use of data obtained during the study by others. Therefore, placing the data into a GIS format is a major component of our program. The GIS format allows us to record the various data collected during the study as “features” (e.g., a dormant landslide), combine similar features into individual “layers” (all dormant landslides), and assign “attributes” (observed information such as approximate age, thickness, etc.) to each feature. The power of the GIS is that these layers contain the spatial location of the mapped features, and can therefore be digitally stacked on top of each other to display data and explore relationships between different types of features.

For this project, numerous GIS layers were created for the geologic, landslide-related and fluvial-geomorphic assessments. The data organization and attributes are shown in Table 1. Examples of our GIS layers include features such as historically-active landslides, gullies, and geologic units. Each feature recorded in the landslide and fluvial layers was assigned numerous attributes, such as type, general age, and depth, based on a pre-established method of assessment. Features were captured and placed into one of three types of layers: those which could be delineated at map scale were recorded as "polygons," while features less than approximately 100 feet in width or diameter were placed in "line" and "point" layers, respectively. For ease of reference within this report, features too small to delineate at map scale may be referred to as "small" while those large enough to map at 1:24,000 scale could be referred to as "larger."

The various geologic layers created within the GIS (and feature type) include: *geologic units* (polygons); *contacts, faults, lineaments and structural axes* (lines), and; *strike and dip, springs, etc* (points). For the landslide inventory, a separate set of GIS layers was produced for each year of photographs used (1981, 1984 and 2000). Each landslide-related set contains multiple layers, including but not necessarily limited to: *historically-active slides* (polygons); *dormant slides* (polygons); *slides* too small to map at scale (lines and points); and "*symbology,*" which includes graphical representations such as arrows showing direction of movement, head scarps and queried landslide boundaries. Geomorphic features related to landsliding, including *debris slide slopes* (polygons), *disrupted ground* (polygons) and *inner gorges* (lines), were mapped from the 2000 air photo set. Fluvial-geomorphic features mapped for both 1984 and 2000 photo years are contained in *mapped channel characteristics* (polygons, lines, and points), and *gullies* (lines) layers, while those prepared from one set of photos (2000) include *alluvial contacts* (polygons), and *Rosgen channel classification* (lines). These layers were digitally "stacked" in a specific sequence to create the geologic and landslide-inventory map (Plate 1), and were instrumental in formation of our landslide potential map (Plate 2).

As previously mentioned, these data layers are related to each other based on the location of the various features, allowing for comparative analyses between the different types of data. For instance, landslides within a region of concern can be tabulated, and the proportion of those landslides matching some parameter (such as type of movement, age, distance from some feature, etc.) can be determined. Similarly, the occurrence of features such as gullies can be compared against the extent of other features, such as geologic units. The database structure allows the geologist to explore these relationships and display the results visually, creating tables, histograms, and maps. One of the main themes of our findings section is the combination of various bedrock geomorphic units, mapped by McLaughlin and others (2000), into hard, moderate or soft terrains, and the relative degree of various landslide and/or fluvial features found within those terrains. We have prepared several figures, tables, charts and histograms illustrating the important relationships in the study area, and our findings are presented in the section entitled “Investigation Findings.”

Map of Landslides and Geomorphic Features Related to Landsliding

The vast majority of the landslide and geomorphic interpretations was made through the examination of stereo-paired aerial photographs using a mirrored stereoscope. Interpreted data were transferred from the photos to the GIS either through direct "heads-up" digitizing on screen, or via mylar overlays that were then scanned and digitized. Two sets of aerial photos were reviewed for the Mattole River watershed assessment. The most recent available photographs (WAC, 2000) are black and white, at a nominal scale of 1:24,000. Aerial photos from 1984 are also black and white, at a nominal scale of 1:31,680. Additional aerial photographs (USDA, 1965; DOD, 1940/1942) that had been scanned and placed on compact disks were provided to us late in the photoassessment stage. These images were used in select locations to verify or disprove hypotheses on the presence, age and/or confidence of interpretation of landslide-related features. Protocols used for mapping landslide type and activity are described above. Finally, data from the previous CGS watershed-mapping program were incorporated into the NCWAP program database, as described below.

Historically-Active and Dormant Landslides

Due to better photo quality and smaller scale, landslides were first mapped on the 2000 photos. The 1984 photos were then examined to determine whether additional landslides could be located and whether a given slide appeared larger or smaller. If a landslide observed on the 1984 photos appeared to be the same as had been mapped from the 2000 photos, it was generally not added to the 1984 layer. Thus, the 1984 layer does not include all the landslides observed in these photos, but only those that were not observed in the 2000 photos, or that appeared to differ significantly between the two sets of photos. Debris slide slopes and inner gorges were mapped using the 2000 photos; remapping of these features on 1984 photos was not needed, since the geomorphic features are not expected to have changed significantly during that time period.

Historical Landslide Mapping by DMG

Spittler (1983, 1984) conducted similar mapping in several 7.5’ quadrangles within the study area as part of DMG’s previous Watersheds Mapping Program (Bedrossian, 1983; DMG, 1999). Those quadrangles include Capetown, Taylor Peak, Buckeye Mountain, Bull Creek, Briceland, and part of Honeydew (see Figure 1 for quadrangle locations). This important data source was checked during the photointerpretation stage, and specific data from those maps were included within the final database as follows: 1) all "small" slides were retained; 2) debris flow/torrent tracks not captured in the 1984 or 2000 photo review were added; 3) the "larger" historically-active and dormant slides mapped by Spittler (1983, 1984) were added only if they appeared to be independent from those observed on the 1984 and 2000 air photos; and 4) due to changes in the program definition of dormant and active, debris slides and debris flows/torrent tracks previously mapped as dormant were reclassified to historically-active. This effectively resulted in partial coverage from a third set of air photos (dated 1981) being included within our assessment.

Inner Gorges

Inner gorges were identified from the 2000 air photos based on breaks in slope or active zones of debris sliding along stream channels. Where map scale permitted, inner gorges were mapped on each bank if appropriate; where the inner gorge was too narrow to differentiate the separate banks at 1:24,000 scale, a single symbol was drawn along the stream channel.

Debris Slide Slopes

Debris slide slopes were visually identified on the 2000 air photos using geomorphic form, including slope and characteristic topographic concavity. Slope maps created in the GIS from the 10m DEM were also used to highlight the steepest slopes. This slope map was used to augment and provide a check of the air photo interpretation.

Disrupted Ground

Areas where sliding was too numerous and/or prevalent to individually delineate and those where the disturbed nature of the ground could not be positively attributed to a specific landslide process were collectively mapped as disturbed ground. This interpretation of ground conditions was gleaned primarily from the 2000 aerial photographs, and augmented with similar mapping by Spittler (1983, 1984) in selected locations.

Landslide Potential Map

Once relevant relationships between geology and landsliding were recognized, a landslide-potential map was created (Plate 2), using the GIS as a tool to capture the geologists' interpretation of relative landslide potential within the study area. The landslide-potential map was generated using a decision matrix (Table 2) prepared by CGS geologists. The matrix format is similar to, and ranking criteria are consistent with that developed for other watersheds within the NCWAP program and used in other CGS programs, but has also been crafted to reflect conditions within the study area. The landslide-potential map was generated at a scale of 1:24,000, the same as the geologic and landslide-inventory map.

Elements considered, interpreted, and applied iteratively within the GIS by the geologists include: 1) the occurrence and distribution of historically-active and dormant landslides, debris slide slopes and disrupted ground; 2) actively-eroding areas such as inner gorges and gullies; 3) geologic conditions relative to steepness and observed behavior of slopes within the study area, and 4) SHALSTAB values (Deitrich and Montgomery, 1999) suggestive of additional potential debris flow source areas. Dependent on the nature of these elements, landslide potential was categorically assigned, ranging from 1 (very low) to 5 (very high). Where differing criteria resulted in a region being assigned different potential values, the highest ranking was used on the map.

Following this matrix, an ArcInfo grid of landslide potential was created, reflecting relative potentials assigned according to geologic units, dormant landslides, debris slide slopes, disrupted ground, and slope. The thematic layer was then exported and converted to an ArcInfo polygon coverage. A nearest-neighbor smoothing function was applied, and individual polygons smaller than 2000 square meters (approximately half an acre) were eliminated. Results from the SHALSTAB slope stability model (Deitrich and Montgomery, 1999) for the watershed was provided to CGS by FRAP. Areas with SHALSTAB values suggestive of potential debris-flow source areas were then compared against debris slide slopes and added to the landslide-potential coverage when deemed appropriate. Historically-active landslides, gullies and inner gorges were then incorporated into the final landslide-potential coverage. Several minor adjustments to the matrix were made during its finalization to ensure that the resulting potential map reflected the geologists' interpretation of relative conditions within the study area. The landslide potential shown on the map does not discriminate by type of mass movement.

Fluvial-Geomorphic Assessment

A reconnaissance-level, fluvial-geomorphic study was made of the Mattole River watershed to document the geomorphic characteristics of the streams and upland areas. Our assessment focused primarily on mapping specific stream features associated with sediment source, transport and response (depositional) areas within the watershed (Appendix 3). Fluvial-geomorphology data sets collected for this study were developed from observations of 1984 and 2000 aerial photographs that cover the entire watershed, and are described below. Older photographs were spot-checked in selected portions of the watershed to confirm interpretations. Features identified during the air photo interpretation were transferred manually to mylar overlays using USGS 7-1/2 minute quadrangles as base maps. The mylar overlays were then scanned, digitized and georectified to facilitate comparison of the features with other data sets collected during our study.

The general processes used to capture the fluvial-geomorphic features are described below. A more detailed description of these methods can be found in CGS's *Draft NCWAP Methods Manual* (April 6, 2001).

Alluvial Contacts

Quaternary alluvial units were remapped for this project using aerial photographs and topography to delineate geologic units associated with the stream network. Map units were assigned relative ages, based upon crosscutting relationships, development of vegetation, and height above the active stream channel. Upon completion of the assessment, these map units were incorporated into the geologic map, replacing the more general alluvial units mapped by McLaughlin and others (2000). In addition, the gravel-bar network was mapped and used to help define the active stream channel (defined as having a flood return period of approximately 100 years). This information includes active point, lateral, mid-channel and junction bars that could be distinguished at map scale, and their vegetated equivalents.

Gullies

Gullies mapped from 1984 and 2000 air photos for this project include those that appear historically active, with little to no vegetation within the incised area. Most gullies that could be identified on the air photos were located in sparsely vegetated and/or grassland areas where the ground surface is observable. This creates a potential bias in the mapping of this feature, because gullies beneath canopy are not as visible. However, in this study area, grassland areas usually overlie relatively erodible geologic material, such that a prevalence of gullies in those areas could be expected. Regardless of potential bias, it is important to document these sediment source areas wherever they can be identified, and multiple year mapping helps define areas of ongoing surface erosion.

Rosgen Channel Classification

Channel types were characterized within the study area using a reconnaissance-level interpretation based on Rosgen (1996) channel type. The Rosgen classification system (Figure 6) uses three-dimensional properties (entrenchment ratio, width/depth ratio, and sinuosity) to distinguish between stream types. The entrenchment ratio is a computed index value describing the degree of vertical containment of a channel. It is defined as the ratio of the flood-prone width to the bankfull channel width. The width/depth ratio reflects channel cross-section shape; it is defined as the ratio of bankfull channel width to mean bankfull depth. Finally, sinuosity is identified as the ratio between stream and valley lengths. These properties are best determined by field measurements; however, for this study they were estimated from air photos and topographic base maps.

Rosgen stream type is further subdivided based on channel slope. For this study, the 10m DEM was used to code the stream drainage network for gradient based on Rosgen class gradient breaks (0.1%, 1%, 2%, 4%, 10%). The final level of Rosgen classification, differentiating by channel materials, could not be estimated using air photos.

Mapped Channel Characteristics

Thirty-two types of stream characteristics ("mapped channel characteristics; MCCs") were considered in the aerial photograph review, and added to the fluvial database where observed (Table 3). That list of channel characteristics includes features that are indicative of channel instability (e.g., eroding banks) and sediment storage (e.g., mid-channel bars), as well as other general channel attributes such as pools or riffles. Those indicative of excess sediment production, transport, and/or response (deposition) are referred to as "negative" mapped channel characteristics (NMCCs) within this report and are shown in boldface type on Table 3.

Within the database, channel characteristics were listed in order of importance for influencing the stream channel. The primary characteristic field (Sed type 1 in the attribute fields) represents that channel characteristic best reflecting conditions observed throughout the mapped channel reach. The secondary characteristic fields (Sed type 2, 3 and 4 in the attribute fields), records channel characteristics also observed within the reach, if present, but they were considered to be of subordinate importance. Images of these mapped features are presented and described in the "Photographic Dictionary of Mapped Channel Characteristics" (Appendix 3).

INVESTIGATION FINDINGS

For the purposes of the NCWAP synthesis report, the Mattole watershed was split into five subbasins – estuary, north, east, south, and west. These subbasins were defined using Calwater 2.2a planning watersheds (PWs), which are shown in Figure 2. CGS's study area also includes the coastal basins to the west of the Mattole watershed. The text below describes the findings related to the entire study area first, followed by those relevant to individual subbasins.

The geologic structure of the study area is characterized as having a generally northwest-southeast trend, more or less parallel to the tectonic sutures between the Central belt and Coastal belt and between the three tectonostratigraphic terranes within the Coastal belt. This general trend is manifest in the orientation of the coastline, the northwest-flowing Mattole River, and in the outcrop patterns of some of the bedrock units. Imposed on this northwest-trending structure is a random distribution of intact blocks within a sheared matrix, which characterizes much of the Franciscan Complex. The topography of the King Range is a result of the active tectonic processes associated with the Mendocino Triple Junction. The highest relief and the steepest slopes are found in the Big Creek and Shipman Creek planning watersheds (Figure 2), coincident with the area of most rapid tectonic uplift.

Geomorphic Terrains

The distribution of landslides, geomorphic features, vegetation, and other features are strongly influenced by the underlying geology. The geologic map by McLaughlin and others (2000) distinguishes 26 bedrock units within the study area based on tectonostratigraphic terrane, lithology, structure, and topographic form. Based on the similarities in topographic form distinguished by McLaughlin and others (2000), and on the density of mapped landslides (Table 4), we have consolidated these bedrock units into three groups, herein referred to as hard, moderate, and soft "geomorphic terrains" (see Ellen and others, 1982). Specifically, the bedrock map units have been grouped into geomorphic terrains as follows:

> <u>Soft Terrain</u> – Geologic subunits identified as having the greatest landslide density (cm1, serpentinite, and co1). Units cm1 and co1 are described as having "rounded, irregular, generally lumpy, and largely gently sloping topography that lacks a well-incised system of sidehill drainages. Units with these characteristics correspond to mélange and other sheared rock that contains abundant clayey, penetratively-sheared argillite" (McLaughlin and others, 2000). The soft terrain underlies approximately 23% of the study area.
>
> <u>Moderate Terrain</u> – Geologic subunits identified as having intermediate landslide density (y1, co2, and krk1), along with the small units of different lithology (e.g., cols, krb) that collectively underlie less than 1% of the study area. Units y1, co2, and krk1 are described as generally having "irregular, gently to moderately sloping topography that lacks a well-incised system of sidehill drainages. These units correspond to mélange having subequal amounts of sandstone and argillite or to highly folded and variably sheared, predominantly argillitic sequences" (McLaughlin and others, 2000). The overlap deposits (QTw on the map) are late Cenozoic in age, and are weakly- to moderately-well lithified rock. Therefore, these rocks are unlike the unconsolidated Quaternary deposits, and are included in the moderate terrain. Moderate terrain underlies approximately 34% of the study area.
>
> <u>Hard Terrain</u> – Geologic subunits identified as having the lowest landslide density (y2, y3, co3, co4, krk2, and krk3). These units are described as having steep topography with sharp or generally sharp crests and well-incised sidehill drainages that may be regular or irregular, corresponding to the least disrupted rock masses and containing the smallest proportion of

clayey, sheared argillitic rock (McLaughlin and others, 2000). Hard terrain underlies approximately 37% of the study area.

The unconsolidated Quaternary deposits mapped overlying the bedrock are grouped together as a fourth geomorphic terrain, which underlies approximately 7% of the study area.

The logic of grouping the various geologic units is shown in Table 4, where the 26 geologic units are listed in order of landslide density. The Quaternary deposits have the lowest landslide densities. For the major bedrock subunits that are distinguished by topographic form (those distinguished by the numerals 1-4), the sequence by landslide density parallels exactly the progression in topographic form and inferred degree of disruption described above (McLaughlin and others, 2000). Consequently, the soft, moderate, and hard geomorphic terrains consistently reflect both rock condition and landslide density, and landslide density can therefore be used to characterize break points between the three bedrock terrains (Table 4). For example, 44% to 49% of the areal extent of each of the three soft subunits is involved in mapped landslides, while between 22% and 30% of the total area underlain by each of the major moderate subunits is involved in mapped landslides.

We recognize that correlating landslide density to terrain form contains some circular reasoning. For example, soft terrain probably has “rounded, irregular, generally lumpy, and largely gently sloping topography” (McLaughlin and others, 2000) largely because it is affected by abundant landslides. However, the subunit mapping was conducted using small-scale air photos in order that individual landslides would have been more difficult to identify, and the overall character of the terrain could be discerned (Ellen and others, 1982). Furthermore, regardless of how the subunits were initially mapped, they do correlate to landslide density. Therefore, the geomorphic terrains as broken out (Figure 7) provide a simplified division of the watershed based on geology and landform that is useful in the analysis of landslide occurrence and other related spatial data.

Landslide Distribution

The distribution of historically-active (younger than approximately 100 to 150 years) and dormant landslides in each of the hard, moderate, and soft terrains is shown in Figures 8, 9, and 10. These figures show visually that the greatest density of landslides is captured in the soft terrain, and that hard terrain is less affected by landsliding than the other bedrock terrains. Table 5 shows these same relationships quantitatively, and Table 6 shows these relationships for all mapped landslides, historically-active and dormant. Across the study area, approximately 44% of the soft terrain is involved in mapped landsliding (dormant or historically-active), as compared to approximately 26% of the moderate and

11% of the hard terrain (Table 6). Tables 7 and 8 show the distribution of landslides by subbasin.

Landslide Type

Landslide type is also correlated to geomorphic terrains. This relationship is depicted in Figure 11, which shows a histogram of geomorphic terrain underlying each type of historically-active landslide. For instance, historically-active earthflows occur predominantly in soft terrain. While soft terrain underlies only approximately 23% of the study area, approximately 83% of the total areal extent of historically-active earthflows is contained within the soft terrain. Conversely, less than 4% of these earthflows are found in hard terrain, despite a greater portion of the study area being underlain by hard terrain than by soft. Similarly, historically-active debris slides are more prevalent in moderate and, to a lesser degree, hard terrain. This line of analysis breaks down for dormant landslides. Debris slides and debris flows older than approximately 100 to 150 years are very seldom preserved in the landscape, while earthflows are more likely to remain active than are rockslides. Thus, mapped dormant landslides, particularly those classified as dormant-mature or dormant-old, are dominated by rockslides, regardless of terrain.

The data presented in Figures 11 and 12 also show that landslide processes in moderate terrain are similar to those in hard terrain. Specifically, both moderate and hard terrains are more affected by debris slides and little affected by earthflows. For each type of landslide, a greater area is affected by historically-active landsliding in the moderate terrain than in the hard terrain (Figure 11), although the relative importance of landslide type is similar in both terrains (Figure 12). In total, more than twice as much moderate terrain is involved in historically-active landslides compared with hard terrain, despite the two terrains being comparable in overall area. These data suggest that a given rock type underlying both moderate and hard terrains is fundamentally similar, differing in the degree of structural disruption and resultant landslide susceptibility.

Conversely, soft terrain is more affected by earthflows and little affected by debris slides (Figure 12, Table 5). These data show that the underlying material is physically and mechanically distinct from the hard and moderate terrains, and that slopes underlain by soft terrain typically fail by different mechanisms. The difference in slope failure mechanisms reflects the strongly sheared, clay-rich mélange material that is characteristic of the soft terrain.

Mapped gullies also correlate with geomorphic terrain. Figure 13 shows the areal distribution of gullies across these terrains. The majority of mapped gullies (approximately 75%) are found in the soft terrain. This result is interpreted to reflect actual conditions, due to the relatively easily-erodible nature of the soft terrain, although we acknowledge that we can recognize gullies more readily in the open grasslands characteristic of the soft terrain than we can under canopy typically present on the moderate and hard terrains.

Slope

Slope also varies according to terrain. A map showing the distribution of slope across the study area is shown in Figure 14, and a histogram showing the distribution of slope according to terrain type is shown as Figure 15. These figures illustrate that the slope distributions for moderate and hard terrains are similar, but differ from that of the soft terrain. The slope distribution becomes progressively skewed toward lower slopes from hard to soft terrain. The mean slopes within hard, moderate and soft terrains are 53%, 49%, and 38%, respectively.

The slope distribution within the Quaternary units is entirely different from that within bedrock units. This is because bedrock units reflect erosional processes, with a distribution of slopes between flat-lying and vertical, while Quaternary units reflect depositional processes, resulting in predominantly very low to low slopes.

Ridgetop-Spreading Features

Classic, well-formed ridgetop-spreading features are evident in several portions of the study area, particularly near the coast. These features are thought to be caused by lateral spreading and settlement of ridges triggered by earthquake shaking (Hart, 1996).

On the coastal slope of the Whale Gulch planning watershed (Figure 2), northwest-trending lineations with back-facing scarps on a number of spur ridges are visible on air photos. These are interpreted to be either small strike ridges aligned parallel to the King Range thrust fault, or ridgetop-spreading features distributed across the upper half of the slope. Well-developed ridgetop spreading was also observed along the northern edge of McNutt Gulch and Joel Flat planning watersheds (Figure 2). Smaller ridgetop-spreading features were observed distributed across Shubrick Peak and Petrolia quadrangles.

Several northeast-trending ridgelines south of Cooskie Creek have well-formed ridgetop-spreading features observable from air photos. Some of these are clearly associated with landslides that cover the entire slope, from ridgeline to stream. The large landslide complex on the south face of Taylor Peak also appears to be related to the well-developed ridgetop-spreading features noted at the top of this peak. These observations suggest a continuum between ridgetop spreading and deep-seated landsliding within the study area (Hart 1996).

Inner Gorges

The extent of inner gorges within the watershed was compared against the extent of blue-line streams because the latter represents a consistent depiction of major streams across the watershed. In order to conduct analyses of possible interrelationships between inner gorges and other features, modifications to the inner gorge layer were necessary. Where inner gorges cross areas underlain by Quaternary alluvium, it was assumed that a thin veneer of sediment lay above bedrock. Therefore, those inner gorges were assigned to the underlying bedrock terrain for analysis purposes. Additionally, it was universally assumed that inner gorges were superseded by overlying historically-active debris slides when those slides extended farther upslope than the inner gorge. Therefore, inner gorges are not shown to cross historically-active debris slides on Plate 1, and the measured lengths of inner gorges used in our assessment of potential interrelationships between features reflect this interpretation. In order to calculate lengths of inner gorges along stream channels, it was necessary to convert the ”double-sided” inner gorges into a single linear feature that represents the length of stream channel occupied by the “double-sided” inner gorge feature. Otherwise, due to the linear nature of the inner gorge in the GIS, the length of double-sided inner gorges would have been counted twice in our analyses. Using their best judgment, the CGS engineering geologist selectively removed a portion of, or the entire length of, one side of the double-sided inner gorge such that the resulting single-sided feature(s) would be attributed to the same subbasin and geologic terrain(s) as occupied by the double-sided feature.

Looking at the study area as a whole, inner gorges have formed along about 42% of the blue-line streams in the bedrock terrains (Table 9). Inner gorges are about evenly distributed throughout the study area. That is, the percentage of total inner-gorge length identified within each subbasin is similar to the percentage of all blue-line streams within that subbasin (compare Table 10 to Table 9).

In many areas, inner gorges extend upstream of blue-line streams or were mapped along small streams that were not included in the blue-line stream file. This departure is greatest in the hard terrain with an average of 20% more inner gorges than blue-line streams, and in the Northern subbasin, where about 24% of inner gorges were mapped outside of blue-line streams.

Inner gorges are most common along blue-line streams in the hard terrain throughout the study area (Table 9). Whereas approximately 41% of bedrock blue-line streams occur within the hard terrain, about 47% of the total length of inner gorges was mapped in that terrain. In the moderate terrain, inner gorges have formed along an average of 40% of the blue-line streams. Inner gorges are least common in the soft terrain where they have formed along an average of 34% of the blue-line streams.

Landslide Associations

In this section, we describe relationships between several landslide attributes. Only strong correlations or important relationships are described. The dominant relationships between landsliding and geomorphic terrains are described above, under the heading "Landslide Distribution."

Approximately 73% of all historically-active landslides (by count) were interpreted to have delivered sediment to the stream network. This stream network includes blue-line streams as well as smaller drainage coarses visible on air photos. Those landslides that delivered sediment are shown in Figure 16.

Approximately 32% of all mapped historically-active debris slides (by count) were observed proximate to roads. This does not necessarily mean that the road caused the landslide, only that we observed a road near the debris slide. Of these debris slides observed adjacent to roads, approximately 71% delivered sediment to streams. In comparison, approximately 77% of the mapped historically-active debris slides and debris flows <u>not</u> observed proximate to a road were interpreted to have delivered sediment to streams. This analysis was conducted using data from 1984 and 2000 air photos. Data from the previous watershed mapping (Spittler, 1983, 1984) were not assessed because attributes such as proximity to roads or delivery to streams were not recorded for this earlier data.

Approximately 73% of the area occupied by identified historically-active debris-slide and debris-flow lies within the third of the study area mapped as debris slide slopes. Thus, debris slide slopes are effective in capturing the potential for debris sliding.

Approximately 23% of the area occupied by mapped historically-active landslides is also underlain by mapped dormant landslides. Approximately 19% of the entire study area is underlain by dormant landslides, and therefore approximately 19% of historically-active landslides would be expected to fall within dormant landslides if there were no relationship between historically-active and dormant features. This relationship suggests that historically-active slides, as mapped, may be slightly more likely to occur within dormant landslides.

Landslide Potential

We recognized the patterns of landslide distribution in the study area by assessing the landslide distribution and geomorphic maps, as discussed above, then developed the landslide-potential map (Plate 2) to portray those patterns. This was done by assigning landslide potential based on 1) geomorphic terrain; 2) mapped landslides and geomorphic features; and 3) slope. The assigned values are shown in Table 2.

Areas of historically-active landslides and inner gorges were considered to have the highest potential, while flat-lying alluvial areas were assigned to the lowest category of potential. Slope, the presence of mapped geomorphic features, and inferred relative strength of the geologic material were used to grade areas between these two end members. For example, steep slopes in moderate terrain were generally considered less stable than similar slopes in hard terrain. Similarly, slopes occupied by dormant landslides or soft terrain were considered less stable than similar or somewhat steeper slopes in moderate and hard terrain.

The landslide potential map, shown in Plate 2, is dominated by landslide-potential categories 3 through 5. We consider this result reasonable in this geologically-active watershed. Relative to other watersheds, little of this watershed is considered to have low potential for landsliding, although some is identified on the alluvial valley floors and the flat ridgetops.

The distribution of landslide potential within the Mattole study area is shown in two histograms: Figure 17 depicts landslide-potential distribution within the six subbasins, and Figure 18 depicts landslide-potential distribution within the geomorphic terrains. Overall, approximately 52% of the study area has high to very high landslide potential (Figure 17). Slightly more than 60% of both the coastal and northern subbasins is considered high and very high landslide potential, while the southern subbasin contains only approximately 24% high and very high landslide potential. These areas represent our interpretation of the sites with the highest potential for future landsliding, and therefore, the areas where fluvial sediment is most likely to originate. This relationship is further discussed below, under the heading "Spatial Relationship to High Landslide Potential."

Fluvial Geomorphology

The distribution of fluvial features recorded during our study was evaluated with respect to the extent of blue-line streams within the watershed. The blue-line streams were chosen because they are a consistent depiction of the major streams within the network, and a digitized file was available. The Mattole watershed contains about 692 miles of blue-line streams, with an additional 155 miles in the Coastal basins, for a combined total of 847 miles in the study area (Table 10). The river system within the Mattole watershed is arranged in a contorted or irregular drainage pattern. The mainstem of the Mattole River flows in a general northwesterly direction, parallel to the structural grain of the Franciscan Complex. Tributaries to the mainstem flow generally to the northeast or southwest, perpendicular to the Mattole River, and often the larger tributaries branch upstream into channels that trend parallel to the mainstem. In the Coastal basins, the streams form a dendritic drainage pattern with the trunk streams flowing directly toward the coastline. This pattern is typical of uniformly resistant rock and results from the fact that virtually all of the Coastal basins consist of moderate and hard terrains, which tend to exhibit generally similar competence and slope stability properties.

Stream Density

Streams are about evenly distributed spatially throughout the subbasins of the study area. That is the cumulative lengths of streams within a subbasin, expressed as a percentage of the total stream length for the study area, is similar to the area of each subbasin expressed as a percentage of the total study area. The stream density calculated for the entire Mattole study area is 2.3 (miles/square mile). Stream density varies considerably between areas underlain by bedrock and alluvial terrains; these density values form the point of comparison for portions of the study area. The results are presented in Table 10.

Within bedrock terrains, stream density across the entire study area is 1.9 and, dependent on subbasin, varies between 0.9, and 2.1 (miles/square mile). Stream density varies within the three bedrock terrains, with higher densities found in the harder terrains. Specifically, stream densities within the moderate and hard terrain average 1.9 and 2.0 respectively. Stream densities within the soft terrain average 1.7.

Stream density within the Quaternary deposits is 7.3 (miles/square mile), and ranges by subbasin from a low in the Coastal subbasin 3.0 to a high in the Eastern subbasin of 12.5. These relatively high stream densities in the Quaternary deposits are expected, because the relatively small area underlain by Quaternary deposits (7% of the study area) is preferentially located along the longer, larger streams, particularly the mainstem Mattole.

Rosgen Classification

The Rosgen (1996) classification system (Figure 6) was applied by CGS to all blue-line streams within the Mattole study area using aerial photographs and topographic maps. Channel slope, derived from the DEM, was used to subdivide primary stream types into subcategories. The areal distribution of Rosgen stream classification is shown in Figure 19, and a histogram showing the prevalence of specific Rosgen stream types (Rosgen stream class versus percent of total stream length) within the study area is presented in Figure 20. The two most common mapped stream classes are the A and A+ types, which combined account for about 66% of all blue-line streams. In general, the majority of smaller, lower order tributaries is A and B types. B channels are commonly found in larger tributaries, G and Gc channels in lower tributary reaches, and the majority of the mainstem channel is classified as C type channel.

The Southern subbasin is unique for its abundance of F type streams. This stream type is found along the mainstem Mattole where the river is entrenched within a broad alluvial valley from approximately Thorn Junction to Thompson Creek.

Predictably, the typical Rosgen classes mapped along inner gorges are those characterized as moderately entrenched to entrenched (A, B and G classes). These classes occur more frequently along inner gorges than generally along all of the streams throughout the study area.

Source, Transport and Response Reaches

The spatial distribution of source, transport, and response reaches governs the distribution of potential impacts and recovery times for the stream system. We used channel slope to classify stream sections as source (>20%), transport (4-20%) or response (<4%) reaches. Streams with gradients greater than 20% are considered source areas for sediment, while those with gradients less than 4% are considered areas of sediment deposition (Montgomery and Buffington, 1997). Figure 21 shows the distribution of these slope classes for the Mattole study area.

Source and transport reaches are most common in the bedrock terrains, while response reaches are more common in the Quaternary deposits (Table 11). Virtually all (99%) of the source reaches are found in bedrock terrains and comprise 27% of the total length of blue-line streams. Most of the transport reaches (91%) are found in bedrock terrains and this reach type comprises approximately 36% of all blue-line streams. Response reaches predominate in Quaternary deposits and comprise the remaining 37% of blue-line streams throughout the study area. Whereas the Quaternary deposits account for only 7% of the study area, 51% of all the response reaches were identified in this terrain. Approximately 85% of the streams within the Quaternary deposits are response reaches.

The areas of greatest susceptibility to sediment deposition are those where higher gradient reaches transition into low gradient reaches. For example, a given transport reach could have high velocity and streamflow, resulting in a large carrying capacity for sediment. If the gradient changes to a slow moving response reach, sediment can rapidly fall out and deposit in the channel or along the banks. Examples of this phenomenon can be found at major slope breaks along Lower and Upper North Forks of the Mattole River. A specific example is shown in Figure 22, which is a photograph showing a tributary fan at the confluence of Conklin Creek and the mainstem Mattole River. Response reaches are found primarily in the Quaternary alluvium; these are reaches where sedimentation is most likely to occur.

Negative Mapped Channel Characteristics

A variety of stream features ("mapped channel characteristics"; MCCs') were mapped from aerial photographs for this project. Those characteristics that may indicate excess sediment production or transport are termed "negative mapped channel characteristics" (NMCCs) within this report. In the Mattole study area, the primary difference between MCCs and NMCCs is the inclusion of point bars within the MCCs.

Comparison of what proportion of a stream is occupied by these features was used as an indicator of disturbance, sediment source, or stored sediment in the river system. Quantitative analyses of NMCCs were conducted only on data assigned to the primary characteristic field because this field represents the channel characteristic that best reflected conditions observed throughout the entire mapped channel reach. The areal distribution of NMCCs is shown in Figure 23. The measured lengths and the proportion of streams affected by NMCCs recorded from both 1984 and 2000 aerial photo sets are shown in Table 12.

Negative Mapped Channel Characteristics, 1984-2000

Negative mapped channel characteristics observed on the 1984 photos affected approximately 34% of all blue-line streams (Table 12). In the 2000 photos, the total affected length decreased to approximately 20%. The stream reaches affected by observed NMCCs during these two photo years are shown in Figure 23. In both photo years, the features observed were dominated by wide channels and, secondarily, by displaced riparian vegetation (Figure 24). Figures 25 and 26 visually depict the occurrence of these two NMCCs, recorded as either primary or secondary characteristics for the two photo years.

The overall trend for the Mattole watershed shows improvement (i.e., reduction in the length of observed NMCCs and/or reduction in the percentage of streams affected by NMCCs) in channel conditions for every subbasin between 1984 and 2000 (Table 12). In this time, the total length of NMCCs decreased by a low of 7% in the Northern subbasin to a high of 88% in the Southern subbasin. The largest absolute (actual length) reduction in the length of NMCCs occurred in the Eastern Subbasin. Most of this improvement is seen as a reduction in the proportion of streams affected by displaced riparian vegetation and, to a lesser extent, wide channels (Figure 24).

Similarly, reductions were observed when evaluating the percentage changes in the length of blue-line streams affected by NMCCs. The greatest change was observed in the Southern and Eastern subbasins (18% and 27%, respectively), while the Northern subbasin showed the least amount of improvement (3%). For the entire study area, there was a 40% reduction in the total length of observed

NMCCs, and 14% reduction in the proportion of blue-line streams affected by NMCCs (Table 12).

Despite the overall reduction in length and proportion of streams affected by NMCCs, three segments of the study area showed a small overall increase in these features. The total length of streams affected by negative NMCCs within the soft terrain in the Northern subbasin and within the Quaternary deposits in the Eastern and Western subbasins increased between 1% and 2%. These increases result primarily from a greater amount of wide channels, lateral bars, eroded banks and braided channels observed in the 2000 photos.

Improvements in channel conditions were greatest in the bedrock terrains, with the highest calculated values observed in the hard terrain, and the least amount of improvement recorded for the soft terrain. The total length of NMCCs within the Quaternary deposits remained nearly constant between 1984 and 2000 (Table 12). When compared to the percentage of total stream length within a terrain, these changes in the distribution of NMCCs result in features suggesting excess sediment being disproportionably observed in the bedrock in 1984 and distributed evenly across the entire study area in 2000.

We interpret the concentration and redistribution of NMCCs in streams within Quaternary deposits to suggest that the effects of historic excess sediment input are moving downstream through the river system. The spatial pattern of channel improvements within bedrock terrains implies that the rate of sediment input to the fluvial system has decreased since 1984.

Spatial Relationship to High Landslide Potential

To evaluate a potential linkage between delivery of sediment to streams resulting from slope instability and negative impacts to streams, correlations between NMCCs and streams adjacent to areas of high and very high landslide potential (landslide potential map (LPM) categories 4 and 5) were assessed. The LPM serves as a summary of our understanding of current and future hillslope instability, and therefore potential sediment sources. To facilitate this correlative analysis, NMCCs were represented by those occurring within 150 feet of LPM categories 4 and 5.

In this analysis, only streams and NMCCs within bedrock terrains were evaluated; those within Quaternary deposits were excluded. Streams in the Quaternary alluvium are commonly separated from the surrounding hillslopes by alluvial terraces and floodplains. Therefore, NMCCs observed in alluvial units do not directly result from input into the streams by landslides occurring on the surrounding hillslopes, but rather NMCCs within these alluvial reaches are likely derived from migration of upstream sediment.

Within the bedrock portions of the study area, 75% of the blue-line streams are adjacent to or within LPM categories 4 and 5 (Table 13). This value varies by subbasin according to the proportion of high to very high landslide potential in each subbasin. Within this subset of streams, 47% of streams were affected by NMCCs in 1984, and 26% were affected by NMCCs in 2000 (Table 14).

Throughout the study area, and in both sets of air photos evaluated, the NMCCs within 150 feet of LPM categories 4 and 5 represent between 98% and 100% of all the NMCCs mapped within bedrock terrains (Table 14). Stated another way, for both photo years (1984 and 2000), NMCCs in bedrock terrains have occurred almost exclusively in streams adjacent to or within LPM categories 4 and 5. Our mapping indicates that LPM categories 4 and 5 are in proximity to categories 1, 2 and 3 throughout the bedrock terrains of the study area. Therefore, it appears that only a very small proportion of the sediment currently or recently delivered to streams has been transported any great distance downstream along stream reaches in bedrock terrains. However, sediment has clearly been delivered to the downstream alluvial response reaches in the past, and the measured affected stream length within the Quaternary deposits has remained about constant from 1984 to 2000. These last observations suggest that much of the sediment currently impacting the lower reaches of the mainstem of the Mattole River was delivered some time ago (i.e., prior to 1984), perhaps during major flood events.

Additionally, our mapping indicates that virtually all NMCCs within bedrock terrains of the Mattole study area occur on only 26% (2000) to 47% (1984) of streams adjacent to or within LPM categories 4 and 5. This information indicates that even within LPM category 4 and 5, only a portion of the adjacent streams has been impacted by NMCCs.

Based on the above findings, it appears that in the Mattole Study area there is a clear linkage (relationship) between areas of slope instability and portions of streams with negative sediment impacts. This investigation indicates that some portion of hillslopes with a high landslide potential (represented by LPM categories 4 and 5) have delivered sediment to the adjacent streams (such effects being represented by NMCCs). The fact that NMCCs are not ubiquitous in bedrock streams adjacent to or within LPM categories 4 and 5 indicates that although the entire length of the streams have potentially unstable slopes above them, only a portion of LPM category 4 and 5 is delivering sediment to the streams, and therefore only portions of streams are being affected by sediment delivered by landslides. Furthermore, that portion with NMCCs is declining through time. Areas for further research should include evaluations of which portions of hillslopes in LPM categories 4 and 5 are most likely to deliver sediment to streams, which portions are not, and what measurable attributes could be identified to discern this difference.

Despite this, hillslopes in LPM categories 4 and 5 are clearly the most likely areas for landslides to occur and these landslides have a high potential to be a source of excess sediment to the streams. The relationship between these areas of slope instability and features indicating excess sediment production/transport in the adjacent streams, provides the opportunity to identify which portions of bedrock uplands are most likely to negatively impact streams. For these reasons, hillslopes in LPM categories 4 and 5 need to be identified as areas of special concern. Further refinements in our ability to identify areas of high landslide potential may allow us in the future to more closely define these areas of special concern.

Findings by Subbasin

For the purposes of the NCWAP synthesis report, the Mattole watershed was split into five subbasins – estuary, north, east, south, and west. These subbasins were defined using Calwater 2.2a planning watersheds (PWs), shown in Figure 2. CGS's study area also includes the coastal basins to the west of the Mattole watershed. Our findings are presented below for the subbasins by geology, landslides, and fluvial geomorphology. The primary geologic characteristics of these subbasins are summarized in Table 15. Histograms showing the distribution of terrain, landslide area, and landslide potential are shown in Figures 27, 28, and 17 and 18, respectively.

<u>Estuary Subbasin</u>

The Estuary subbasin is the smallest in the Mattole watershed, covering only approximately 2 square miles in the vicinity of the river mouth (Figure 2). The subbasin includes hillslopes to the north and south of the valley floor, as well as the estuary itself. Approximately a quarter of the subbasin is underlain by the flat, alluvial valley floor.

Geology and Landslides

The bedrock underlying the uplands consists of a variety of subunits within the Franciscan Coastal terrane. The condition of the bedrock is variable, forming a soft to moderate topography of rolling hillsides, moderate slopes and rounded crests. The small area overlooking the coast north of the Mattole River is underlain by intact sandstone and argillite units, forming a hard terrain with a greater proportion of steep slopes.

The estuary of the Mattole River divides this subbasin roughly in half and occupies a wide active channel within a wider valley. The active channel is underlain by Quaternary stream-channel deposits whereas the balance of the valley floor is underlain by low river terraces.

Much of the moderate terrain south of the Mattole River is occupied by a large, dormant landslide complex. A number of dormant rockslides underlie the locally steep slopes on the hard terrain north of the river. A portion of the hard terrain and the adjacent soft terrain to the east is occupied by disrupted ground.

Fluvial Geomorphology

The Mattole Estuary is characterized by a wide valley, with the lowest gradient and widest channel within the watershed. NMCCs were identified along 36% (1984) and 29% (2000) of the alluvial reach of the Mattole River (Table 12); no NMCCs were identified along bedrock reaches in this subbasin. When compared to other subbasins, the Estuary had some of the smallest reductions in NMCCs as a percentage of all the blue-line streams. The system of gravel bars along the lower Mattole has remained about constant between the years 1984 and 2000. Minor changes were observed chiefly with respect to the location and development of vegetated bars.

Between 1942 and 1965, the Mattole Estuary was dramatically widened and large areas of vegetation were lost. However, compared to the 1965 photos, the 1984 and 2000 photos show (1) a progressive increase in vegetation along the south bank, (2) a decrease in the width of the active channel, (3) smaller areas of braided stream channel, and (4) a shift of the active channel to the north bank.

In summary, channel conditions across the subbasin have generally improved between 1984 and 2000, but the alluvial reaches remain impacted by sediment. Most of this improvement is seen as a reduction in the proportion of streams affected by lateral and mid-channel bars. The lack of NMCCs in nearby bedrock stream reaches suggest that excess sediment observed in the Quaternary units was transported from areas upstream of the subbasin.

<u>Northern Subbasin</u>

This subbasin encompasses the area north of the Mattole River, from the estuary upstream to the Upper North Fork of the Mattole. The planning watersheds that make up the Northern subbasin are: Petrolia, Joel Flat, Long Ridge, Apple Tree, Rainbow, Cow Pasture Opening, McGinnis Creek, Camp Mattole, Oil Creek, and Rattlesnake Creek (Figure 2).

Geology and Landslides

The Northern subbasin has the most structurally disrupted and least stable geology within the watershed. The bedrock underlying the Northern subbasin is dominated by weak mélange (subunit co1) of the Franciscan Coastal terrane composed of scattered blocks of intact rock within a matrix of pervasively-sheared argillite and sandstone. This soft geomorphic terrain underlies 43% of the Northern subbasin, as compared with 0 to 19% of the other subbasins

(Figure 27). The mélange is generally too weak to support development of steep slopes. Accordingly, rolling hillsides, moderate slopes and rounded crests have developed over much of this portion of the watershed. Clayey residual soils that are subject to chronic down-slope movement through soil creep tend to develop on the mélange. Grassy vegetation generally develops in these areas of weathered mélange, apparently because conifer and hardwood trees have a difficult time becoming established on the clayey soil. Steep to very steep slopes are present in this subbasin, particularly along the northern and eastern boundaries. These slopes are formed in hard and moderate terrains, and trees are more commonly established in these areas.

An irregular drainage pattern lacking a preferred orientation and spacing has developed on the disrupted bedrock underlying the upper reaches of most streams in the Northern subbasin. The mainstem Mattole and lower reaches of the Upper and Lower North Forks meander within alluvial channels. Extensive terrace remnants of older alluvial deposits and strath surfaces extend over the broad valley bottoms above the active channel.

An abundance of historically-active and dormant landslides of different types have been mapped in the subbasin, including large landslide complexes that involve entire hillsides covering many tens of acres. About 32% of the subbasin is occupied by historically-active or dormant landslides, and approximately 8% of the subbasin is affected by historically-active landslides (Figure 28). These landslides are predominantly found in the soft geomorphic terrain. Accordingly, landslide potential in this subbasin is the highest in the study area, with approximately 61% of the area included in the high to very high potential categories (Figure 17). Delivery of sediment to streams through gully erosion and debris flows associated with larger historically-active and dormant landslides is also prevalent in the subbasin, as are debris slides along drainages and steep slopes within the hard and moderate terrains. In the Lower North Fork, the high rate of sediment input from erosion and mass wasting is reflected in the accumulation of debris and alluvial fans at the mouths of many tributary drainages.

Fluvial Geomorphology

The Northern subbasin is characterized by the highest concentration of mapped gullies and length of MCCs in the study area. Table 16 illustrates the range of these characteristics observed on 1984 and 2000 aerial photographs. The total length of MCCs decreased only slightly from 1984 to 2000. The cumulative length of gullies increased from 259,500 to 771,700 feet during the same period. Lateral-bar development ranged from low to high values within subreach lengths.

Table 12 illustrates changes in the individual NMCCs between 1984 and 2000. There was a 7% decrease in the total length of NMCCs within the subbasin (Table 12), with most of the change coming from reduction in displaced riparian vegetation. Despite this, there was a 5% increase in NMCC length within the soft terrain during this period. Just under half of all blue-line streams that cross bedrock are adjacent to or within LPM Categories 4 and 5 in this subbasin are also affected by NMCCs. Only a small improvement in this measure was observed between 1984 and 2000 (Table 14).

A closer examination of Table 16 reveals that six PWs (Joel Flat, Long Ridge, McGinnis Creek, Petrolia, Rainbow, and Rattlesnake Creek) have shown reductions (ranging from 5% to 25%) in the length of MCCs. Two PWs (Apple Tree and Camp Mattole) have remained about constant between 1984 and 2000, and two others, Cow Pasture Opening and Oil Creek, have shown significant increases (23% and 8%, respectively) in MCCs. The percentage of gullies has increased in all PWs between 1984 and 2000.

Table 17 documents the number of sites and summarizes the lengths of eroding-bank features within the Northern subbasin on the 2000 air photos. In general, stream-bank erosion has been observed within all of the planning watersheds within this subbasin. The number of eroding-bank sites range from one in the Joel Flat PW to 12 in the Rattlesnake Creek PW. Approximately 8,200 feet of eroding bank has been mapped in the Rattlesnake Creek PW.

In summary, eight of the ten PWs within the Northern subbasin have remained relatively constant, or exhibited a significant reduction, in mapped channel characteristics and lateral-bar development between 1984 and 2000. However, the Cow Pasture Opening and Oil Creek PWs have demonstrated an increase in MCCs. All of the planning watersheds have exhibited an increase in the length of gullies during this same period. In addition, several large areas of ongoing sediment deposition were observed along the Lower North Fork near Petrolia and Upper North Fork near Honeydew. These areas of deposition have been attributed to backwater effects with the mainstem of the Mattole River. Stream-bank erosion has been observed within all of the planning watersheds within the Northern subbasin. These sites of stream-bank erosion are commonly associated with areas mapped as inner gorges or historically-active landslides.

Eastern Subbasin

The Eastern subbasin lies on the east side of the watershed, largely to the east of the Mattole River. The planning watersheds that make up this subbasin are: Dry Creek, Westlund Creek, Sholes Creek, Mattole Canyon, Blue Slide Creek, and Eubank Creek (Figure 2).

Geology and Landslides

This subbasin encompasses the widest range of bedrock types and structure in the watershed, including portions of the Coastal terrane, Yager terrane, and Central belt mélange, along with the fault zones that form the boundaries between the terranes. Correspondingly, slope stability and geomorphology vary widely within the subbasin. In general, the bedrock may be described as relatively intact and stable material locally interrupted by northwest-trending zones of sheared mélange and faulting where the rock is much weaker and susceptible to weathering. As with other areas in the watershed, soft terrain consisting of grassland areas impacted by earthflows, soil creep, and gully erosion tend to develop in the mélange matrix and fault zones. These conditions are found along a broad shear zone that extends to the southeast from Honeydew, along Pringle Ridge and on across the Mattole River near Duncan Creek. Similar conditions are found in the upper reaches of Mattole Canyon Creek and Blue Slide Creek where several fault zones and Central belt mélange are present. Steep forested slopes locally impacted by historically-active debris slides and occasional large, deep-seated, dormant landslides are typical in the moderate to hard terrain in this subbasin. Overall, approximately 24% of the Eastern subbasin is occupied by mapped landslides and 6% of the subbasin is occupied by historically-active landslides (Figure 28).

Fluvial Geomorphology

The Eastern subbasin shows the largest reduction in the length of mapped channel characteristics between 1984 and 2000 as well as the largest reduction (27%) in blue-line stream length occupied by NMCCs (Table 12). Table 18 illustrates the range in MCCs, gullies, and lateral-bar development from the 1984 and 2000 aerial photographs. Comparing the two photo sets it can be seen that every PW within the Eastern subbasin has shown a significant decrease in MCCs. The most noteworthy example is illustrated in the Sholes Creek PW, where the length of MCCs decreased by roughly 68,200 feet from 1984 to 2000. Two PWs, Blue Slide and Sholes Creeks, have demonstrated a dramatic reduction in lateral-bar development, which suggests a decrease in excess sediment.

There has been a dramatic reduction in the length of wide channels, and a two-fold decrease in the length of displaced riparian vegetation in this subbasin (Figures 25 and 26, respectively). However, there has been a doubling of the length of gullies within the Eastern subbasin (Table 18). Significant improvement was observed between 1984 and 2000 in the proportion of blue-line streams in bedrock and adjacent to or within LPM 4 and 5 and affected by NMCCs. In 1984, about 70% of such stream reaches were affected by NMCCs, while in 2000 about 20% were affected (Table 14). Considering the low concentration of NMCCs in the upstream Southern subbasin and the increase in NMCCs in the alluvial reaches of this subbasin, it appears that sediment is being produced internally or from the adjacent Western subbasin.

A sizeable area of sediment deposition was observed along Dry Creek immediately upstream from a large landslide. This area of deposition has been attributed to this large persistent slide acting as a point of hydrologic constraint.

The mouth of Mattole Canyon has also been a long-term area of sediment accumulation. This can be attributed to weak rocks and numerous landslides up-canyon, and a reduction of stream gradient near the area of deposition.

Table 19 documents the number of sites and summarizes the lengths of eroding-bank features within the Eastern subbasin. Stream-bank erosion has been observed in all but one of the planning watersheds of this subbasin. The number of eroding-bank sites range from one in the Mattole Canyon PW to 10 in the Sholes Creek PW. Approximately 12,100 feet of eroding bank has been mapped in the Sholes Creek PW.

In summary, observations from the 2000 air photos show that every PW within the Eastern subbasin has shown a significant decrease in mapped channel characteristics since 1984, with all but one PW showing a significant increase in the length of gullies. Stream-bank erosion has been observed within all but one of the planning watersheds within the Eastern subbasin. The majority of eroding stream banks within this subbasin is within the Sholes Creek and Dry Creek PWs. There has been a dramatic decrease in the length of wide channels from 1984 to 2000, and a decrease in the length of displaced riparian vegetation (Figures 25 and 26).

<u>Southern Subbasin</u>

The Southern subbasin includes the uppermost portion of the watershed, above Bridge Creek. Two planning watersheds make up the Southern subbasin: Bridge Creek and Thompson Creek (Figure 2).

Geology and Landslides

The geologic conditions in the Southern subbasin are the most uniform and stable in the Mattole study area. The subbasin is underlain by Franciscan Coastal terrane rocks that are generally less broken and, therefore, more resistant to erosion and slope instability than bedrock in the other subbasins. This condition has resulted in uniformly hard terrain in the bedrock portion of the subbasin. Overall relief is the lowest of the subbasins; however, the relatively stable condition of the bedrock has led to the formation of sharp-crested topography dissected by straight, well-incised sidehill drainages with steep, heavily-forested slopes. In the lower reaches of the larger tributaries and along the mainstem of the Mattole, streams are confined to narrow channels incised within broader valley bottoms that are formed by bedrock strath terraces with a thin mantle of alluvium. Drainage orientations generally follow, or are perpendicular to, the dominant northwest-trending structural fabric of the bedrock in the area.

The more intact condition of the bedrock is reflected in the presence of comparatively few deep-seated landslides in the southern subbasin. Only 2% of the Southern subbasin is occupied by mapped landslides, compared with 17% to 32% in other subbasins in the study area (Figure 28). Seven to ten of the 32 dormant landslides observed from air photos are associated with a narrow, northwest-trending fault zone in the southeastern corner of the watershed. Most of the very limited historically-active mass wasting activity is in the form of small debris slides. Accordingly, the Southern subbasin has the lowest landslide potential of the subbasins, with about half the subbasin classified as moderate potential, and approximately 24% in the high to very high potential categories (Figure 17).

Fluvial Geomorphology

The fluvial geomorphology of the Southern subbasin is characterized by the lowest concentration of mapped channel characteristics, no observed gullies, and low to intermediate values for lateral-bar development. Table 20 illustrates the range of these features observed on the 1984 and 2000 aerial photographs. Subbasin-wide values for NMCCs decreased from 20% of total stream length in 1984 to 2% in 2000 (Table 12). Figures 25 and 26 show the change in NMCCs is primarily due to a dramatic decrease in the total length of wide channels and a smaller but still significant decrease in displaced riparian vegetation during that period. Significant improvement was observed between 1984 and 2000 in the proportion of blue-line streams in bedrock and adjacent to or within LPM 4 and 5 and affected by NMCCs. In 1984, about 64% of such stream reaches were affected by NMCCs, while in 2000 about 7% were affected (Table 14). Gullies were not observed in the aerial photos, and lateral-bar development values are uniformly low within subreach lengths (Table 20).

The Thompson Creek PW has low values for all MCCs, and has shown a 91% decrease in length of MCCs from 1984 to 2000 (Table 20). The Bridge Creek PW has shown an 87% decrease in MCCs during this same period, with no change in lateral-bar development. Stream-bank erosion in the Southern subbasin appears negligible (Table 21).

<u>Western Subbasin</u>

The Western subbasin lies south and west of the Mattole River, and east of the crest of the King Range. The planning watersheds that make up the Western subbasin include: Shenanigan Ridge, Squaw Creek, Woods Creek, Honeydew Creek, North Fork Bear Creek, South Fork Bear Creek, and Big Finely Creek (Figure 2).

Geology and Landslides

The south and central portions of the Western subbasin straddle the boundary between the King Range terrane on the west and the Coastal terrane to the east. The lower portion of both the north and south forks of Bear Creek are subsequent streams that follow the zone of faulting and shearing associated with the structural suture between the two terranes, the King Range Thrust fault (Figure 3). To the west, the dramatic relief and steep slopes of the King Range are a reflection of hard terrain, resulting from the relatively intact and stable bedrock underlying the middle of the mountain range coupled with rapid, ongoing regional uplift.

Overall, approximately 17% of the subbasin is occupied by either historically-active or dormant landslides, a lower proportion than any subbasin except the Southern subbasin (Figure 28). The relatively few deep-seated landslides mapped along the eastern flank of the King Range appear to be dormant. Abundant debris slide slopes have been mapped in this area, along with a moderate number of historically-active debris-slide scars concentrated adjacent to drainages. Historically-active debris slides are common along the portions of Bear Creek that lie along the King Range Thrust fault. West of Honeydew and in the middle reaches of Squaw Creek, bedrock is pervasively disrupted along the broad, west-trending Cooskie shear zone that forms the northern boundary of the King Range terrane. Large deep-seated landslides, historically-active earthflows, and gully erosion on grass-covered highlands have been mapped in association with soft terrain in this area of the subbasin. Similar conditions are found in soft terrain in the lower portion of Honeydew Creek.

Fluvial Geomorphology

The fluvial geomorphology of the Western subbasin is characterized by a highly variable concentration of mapped channel characteristics, the lowest increase in the number of gullies among the subbasins, and a wide-ranging pattern of lateral-bar development (Table 22). Comparison of the 2000 and 1984 air photos reveals that six of the seven PWs within the Western subbasin have shown a significant decrease in MCCs. Wide channels and displaced riparian vegetation decreased dramatically (Figures 25 and 26). Similar to other subbasins, the length of gullies about doubled across the subbasin between 1984 and 2000. Two PWs, Big Finely and Squaw Creeks, have shown notable decreases in lateral-bar development (Table 22), which suggest decreases in excess sediment in those PWs.

Significant improvement was observed between 1984 and 2000 in the proportion of blue-line streams in bedrock and adjacent to or within LPM 4 and 5 and affected by NMCCs. In 1984, fewer than 50% of such stream reaches were affected by NMCCs, while in 2000 about 20% were affected (Table 14). Considering the low concentration of NMCCs in the upstream Southern subbasin and the increase in sediment in the alluvial reaches, it appears that sediment is being produced internally or from the adjacent Eastern subbasin.

The Western subbasin displays a trend similar to the Eastern subbasin in the significant decrease in MCCs between 1984 and 2000. The exception to this trend is found in the Shenanigan Ridge PW, in which mapped channel characteristics have increased approximately 36% since 1984 (Table 22). Areas with a high percentage of MCCs in 1984 include portions of the Honeydew Creek, Big Finely Creek, Squaw Creek, and North Fork Bear Creek PWs. These PWs showed decreases in MCC lengths of between 34% and 76% between 1984 and 2000 (Table 22).

Table 23 documents the number of sites and summarizes the lengths of eroding-bank features within the Western subbasin. Stream-bank erosion has been observed in all but one of the planning watersheds of this subbasin. The number of eroding-bank sites ranges from two in the Shenanigan Ridge PW to 11 in the Honeydew Creek PW. The Squaw Creek PW has been mapped with the greatest total length of eroding banks, approximately 5,700 feet.

<u>Coastal Basins</u>

These planning watersheds lie on the west slope of the King Range. The watersheds drain directly into the Pacific Ocean and do not impact the Mattole River. The planning watersheds that make up the Coastal basins include: McNutt Gulch, Punta Gorda, Cooskie Creek, Big Creek, Shipman Creek, Gitchell Creek, and Whale Gulch (Figure 2).

Geology and Landslides

The geology of the Coastal basins varies from north to south, reflecting the pattern of the entire study area. The drainage pattern is generally perpendicular to the coast, except for Whale Gulch, which extends along the north-south King Range Thrust fault (Figure 3). From Cooskie Creek northward, the area is dominated by weak mélange (subunit co1) of the Franciscan Coastal terrane, composed of scattered blocks of intact rock within a matrix of pervasively-sheared argillite and sandstone. This soft geologic material comprises approximately 14% of the Coastal basins, and 39% of the Coastal basins north of Cooskie Creek, a proportion similar to that of the Northern subbasin. The mélange is generally too weak to support development of steep slopes. Accordingly, rolling hillsides, moderate slopes and rounded crests has developed over much of this portion of the watershed. Clayey residual soils that are subject to chronic down-slope movement through soil creep tend to develop on the mélange. Grassy vegetation generally develops in these areas of weathered mélange, apparently because conifer and hardwood trees have a difficult time becoming established on the clayey soil. These conditions are common in the Coastal basins north of Cooskie Creek.

South of Cooskie Creek, the Coastal basins are underlain by relatively intact bedrock of the King Range terrane. High relief (up to 4,000 feet) and very steep slopes reflect the relatively intact sandstone bedrock of this area and the rapid, ongoing, regional uplift. Approximately 63% of this area is underlain by subunit krk1, which is classified as moderate terrain. King Peak, the highest point in the study area, is underlain by hard terrain. South of Cooskie Creek, approximately one half of the area is underlain by slopes steeper than 65%. Large areas of historically-active debris sliding are found in the Big Creek and Shipman Creek PWs. These historically-active slides are evident in the earliest air photos available (1941), and were noted prior to the 1906 earthquake (Lawson, 1908, p. 390-391). Debris slide slopes and inner gorges are abundant south of Cooskie Creek. Large, dormant-young landslides are common in the Cooskie and Big Creek PWs. Some of these landslides extend from ridgeline to stream, and appear to have developed from ridgetop-spreading features. These may reactivate during major earthquakes.

Fluvial Geomorphology

The Coastal basins are characterized by relatively short streams, with steep gradients and narrow valleys. The basins typically display a wide range in concentration of mapped gullies and a wide range in abundance of mapped channel characteristics, specifically wide channel and displaced riparian vegetation. Table 24 illustrates the range of these characteristics observed on 1984 and 2000 aerial photographs. Overall, NMCCs represent approximately 26% to 19% of the stream length in 1984 and 2000, respectively (Table 12). Significant improvement was observed between 1984 and 2000 in the proportion of blue-line streams in bedrock and adjacent to or within LPM 4 and 5 and affected by NMCCs. In 1984, about a third of such stream reaches were affected by NMCCs, while in 2000 about a quarter were affected (Table 14).

Gully lengths by PW observed in 1984 photos range from 64,100 feet to “Not Observed” (Table 24). Gully lengths within the Coastal basins about doubled in this time frame. Lateral-bar development has uniformly low values.

A closer examination of Table 24 reveals that two PWs (Cooskie and Gitchell Creeks) have shown significant reductions (approximately 40% in each) in the length of MCCs. The change in MCCs in the other five PWs ranged from a 30% increase to a 33% decrease. The total length of gullies has significantly increased (167,100 feet) in three PWs (Cooskie Creek, McNutt Gulch, and Punta Gorda) between 1984 and 2000.

Table 25 documents the number of sites and summarizes the lengths of eroding-bank features within the Coastal basins. Stream-bank erosion has been observed within all seven planning watersheds. The number of eroding-bank sites range from one in the Whale Gulch PW to 11 in the McNutt Gulch PW. The Big Creek PW has been mapped with a total length of approximately 4,700 feet of eroding bank.

In summary, four of the seven PWs within the Coastal basins have shown a significant reduction of MCCs between 1984 and 2000. However, half of the

PWs have exhibited an increase in the number of gullies during this same period. The McNutt Gulch and Punta Gorda PWs have demonstrated an increase in both MCCs and gullies; the Gitchell Creek and Whale Gulch PWs have shown decreases in both features.

Findings for Mattole River Mainstem

This section describes the fluvial-geomorphic assessment of the Mattole River itself. For purposes of discussion, the river has been divided into the lower section, downstream of the Honeydew area, the middle section between Honeydew and the Thorn Junction area, and the upper section above Thorn Junction.

<u>Lower Mattole</u>

The Lower Mattole is characterized by a wide, low-gradient channel with large meanders, occupying a relatively wide valley. The system of gravel bars along the Lower Mattole has remained largely constant between the years 1984 and 2000. Minor changes in such fluvial features as bar development or vegetation have been observed near the confluences with major tributaries. Examples include areas near the mouths of the Lower North Fork and Squaw Creek. An ancient abandoned meander of the Lower Mattole was noted on the air photos near the confluence of Squaw Creek.

<u>Middle Mattole</u>

The Middle Mattole can be divided into two sub-sections near the confluence of Westlund Creek. The downstream reach flows through a distinct, relatively narrow canyon with numerous gradient drops; the upper section has an overall higher gradient. The system of gravel bars along the Middle Mattole has remained relatively constant between the years 1984 to 2000. Minor changes in such fluvial features as bar development or vegetation have been observed near the confluences with major tributaries. Examples include areas near the mouths of the Upper North Fork, Honeydew Creek, Dry Creek, Mattole Canyon, Blue Slide Creek, and Bear Creek. An important event to note is the damming of the Mattole River about a mile upstream of the town of Honeydew by the Honeydew Slide in 1983. A large-volume bar remains at the site of the landslide, and this sediment affects the river downstream toward the town of Honeydew. The effects of the sediment are observed as a wide channel, bar system, and, during times of low flow, a braided river. An ancient abandoned meander of the Middle Mattole was noted on the air photos near the confluence of Sholes Creek.

<u>Upper Mattole</u>

The Upper Mattole predominantly flows within a bedrock channel, and has the highest gradient along the mainstem. In the area from Thorn Junction to

Whitethorn, the Mattole River appears to be confined to a narrow, entrenched channel occupying a wide valley. This is a classic example of an F-type channel defined by Rosgen (1996).

CONCLUSIONS

The primary result of this study is the development of maps (Plates 1 and 2) and a GIS database of landslide, geomorphic and fluvial data. Landowners, land managers, geologists, and public agencies can use these data to assess conditions and relationships on a planning watershed or smaller basis. This report, and the explanations accompanying the GIS data, defines attributes, explains how these data were generated and provides guidance for use of the data.

The Mattole study area is situated in a geologically-active region. Its proximity to the Mendocino Triple Junction and the associated rapid tectonic uplift and frequent strong seismic shaking, in conjunction with zones of weak mélange bedrock, high rainfall and intense storms, result in high rates of natural landsliding and surface erosion. These geologic conditions are particularly notable in the northern portion of the study area.

The geomorphic terrains, as utilized in this report, provide an excellent basis for recognizing landslide-prone areas. The softest terrain (underlain by the weakest mélange units and serpentinite) contains 47% of the mapped historically-active landslide area, yet underlies a relatively small percentage (23%) of the study area. The mode of slope failure is also well correlated with the geomorphic terrains. Large earthflow complexes dominate the soft terrain, while debris slides are found primarily in the moderate and hard terrains.

On the basis of this work, we believe that geologic bedrock (Plate 1), in conjunction with slope, forms the initial criteria for assessing landslide potential. The landslide potential map (Plate 2), which combines these elements with mapped landslides and relevant geomorphic features, should be considered in land-use planning. The high percentage of the study area assigned to categories 4 and 5 (high and very high landslide potential) can be attributed in large part to the abundance of either soft terrain or steep slopes across much of the study area.

The fluvial-geomorphic mapping shows that significant portions of the stream system have been affected by excess sediment. In the 1984 photos, 34% of all blue-line streams were affected by negative mapped channel characteristics. However, by 2000, this measure had improved to 20%. Improvements in channel conditions were apparent in every subbasin, with the greatest improvement observed in the Southern and Eastern subbasins, and least improvement noted in the Northern subbasin. The most dramatic channel improvements were in the reduction of displaced riparian vegetation and, to a lesser degree, wide channels. The latter features in particular may represent a focal point for future research efforts aimed at reducing sediment input into the fluvial system.

In contrast to the improvement in channel conditions in the bedrock streams, little improvement was noted in channel conditions between 1984 and 2000 for streams lying within Quaternary deposits, which are predominantly found along the lower reaches of the stream network. Although we have not identified the specific sources, causes, or timing of sediment input, these features may be related to earlier increased sediment input that is still working its way downstream.

Finally, our analysis of negative mapped channel characteristics in streams adjacent to high and very high landslide potential indicates a high degree of correlation between the two. This suggests that the landslide potential map (Plate 2) can also be used to identify the most likely locations to find impacts resulting from excess sediment in the bedrock stream reaches. However, additional research may be needed to determine what specific portions of the high and very high landslide potential areas are associated with the negative mapped stream characteristics.

LIMITATIONS

This project consisted of a reconnaissance-level review of two sets of aerial photographs taken in 1984 and 2000. Other photo sets would likely reveal additional landslide and fluvial features, as vegetation cover, soil moisture, sun angle, photo scale, and photo quality change with each set of photographs.

Mapping was conducted at a scale of 1:24,000. At this scale, the detection of features smaller than 30 meters in greatest dimension is poor. Small features within forested vegetation often are not revealed on aerial photos. Not only are these small features missed, but a potential bias is added, in that more small landslides may be mapped where trees and brush are not present.

Limited aerial photo coverage may not bracket important watershed events such as major floods, and the effects of such events may not be fully evident in photos taken years later. In particular, debris slides and debris flows are ephemeral features on the landscape, and evidence of their occurrence disappears relatively quickly. Thus, not all debris slides and debris flows that have occurred over historical time are captured in this database. In addition, many fluvial features are changing constantly with changes in stream flow. Thus, the conditions mapped from each set of air photos represent a snapshot in time.

Detailed local mapping of landslides and sediment delivery have been conducted previously by other investigators and/or programs in various portions of the study area. However, time and staffing constraints prevented evaluation of that data.

Due to constraints on access, time, and staffing, field checking of interpretations was minimal. Limited field assessments were performed to supplement aerial photograph interpretation and mapping and improve the capture and analysis of data.

The bedrock geology of MF-2336 has been presented here at a scale of 1:24,000. However, the detail and accuracy of the data are limited to the spatial resolution of 1:100,000 scale in which the digital database was originally compiled by the USGS.

The landslide potential map is a derivative map and therefore includes all the limitations of the several maps from which it was derived. In addition, spatial averaging was applied in generating the landslide potential map. The locations of the resulting landslide potential zones are therefore inappropriate for use on a site-specific basis.

Lack of river stage-flood frequency data and channel cross sections prevented us from assigning flood frequencies to Holocene channel deposits lying outside of the active channel.

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___, dated 3-31-00, Flight WAC-00-CA: Roll 4, Frames 1-15, 83-96, 164-167, and 173-175; Roll 6, Frames 1-21, and 95-113; Roll 7, Frames 1-15, 48-63, 88-104, 135-148, 165-177, 191-201, and 213-219; and Roll 9, Frames 176-191, black and white, vertical, scale 1:24,000.

___, dated 4-1-00, Flight WAC-00-CA: Role 10, Frames 64-67, 70-75, and 77-81; black and white, vertical, scale 1:24,000.

FIGURES

Figure 1. Study area location map. In addition to the Mattole River basin, the California Geological Survey included the adjacent coastal drainage basins as part of the Mattole River Watershed study area. Subbasin boundaries are those used in NCWAP analysis and the Synthesis Report.

Figure 2. Mattole watershed and adjacent coastal areas showing subbasin divisions and Calwater Planning Watersheds (version 2.2a) used by NCWAP.

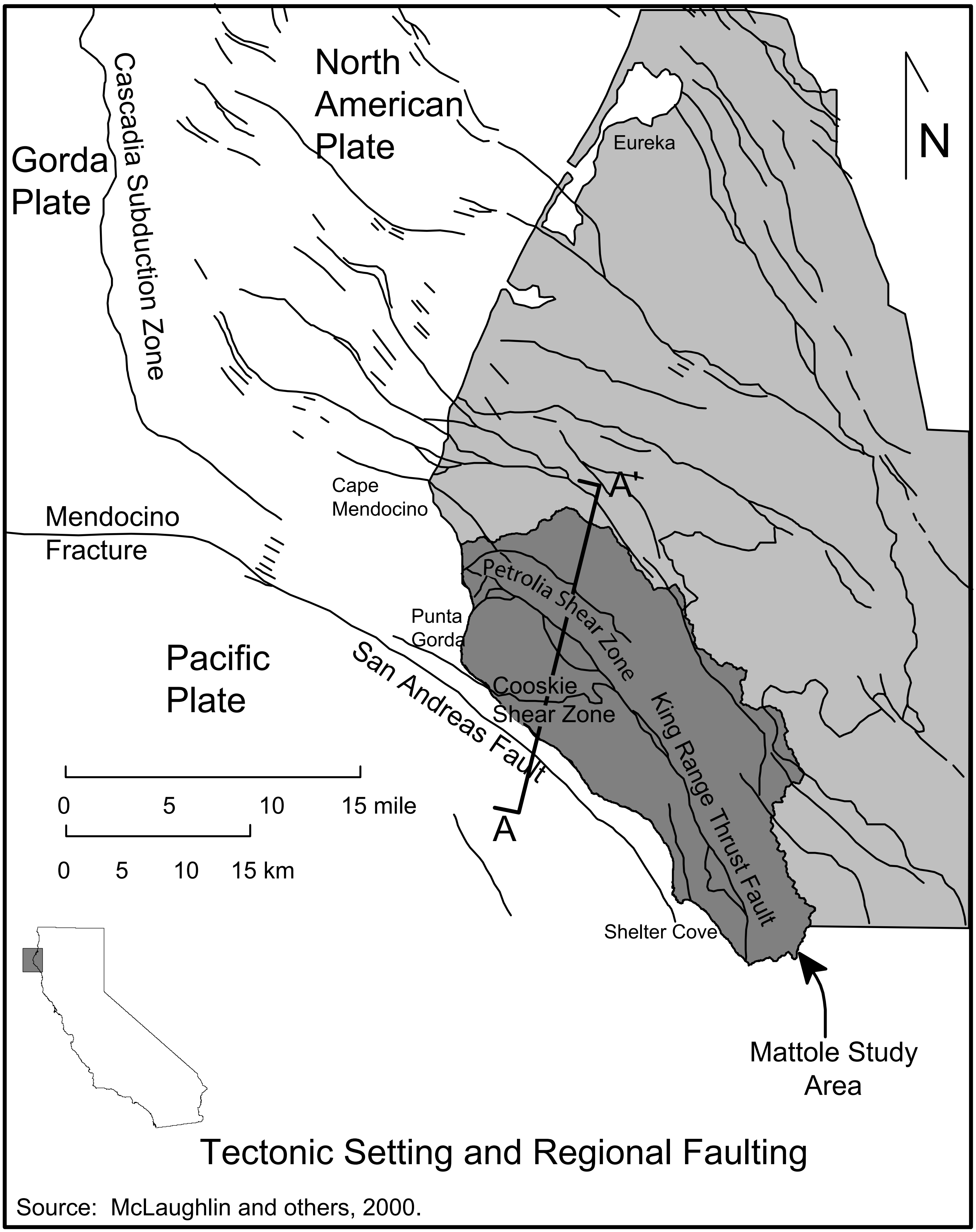

Figure 3. Tectonic setting of the Mattole study area. Line A-A' indicates the approximate location of the geologic cross section presented in Figure 5.

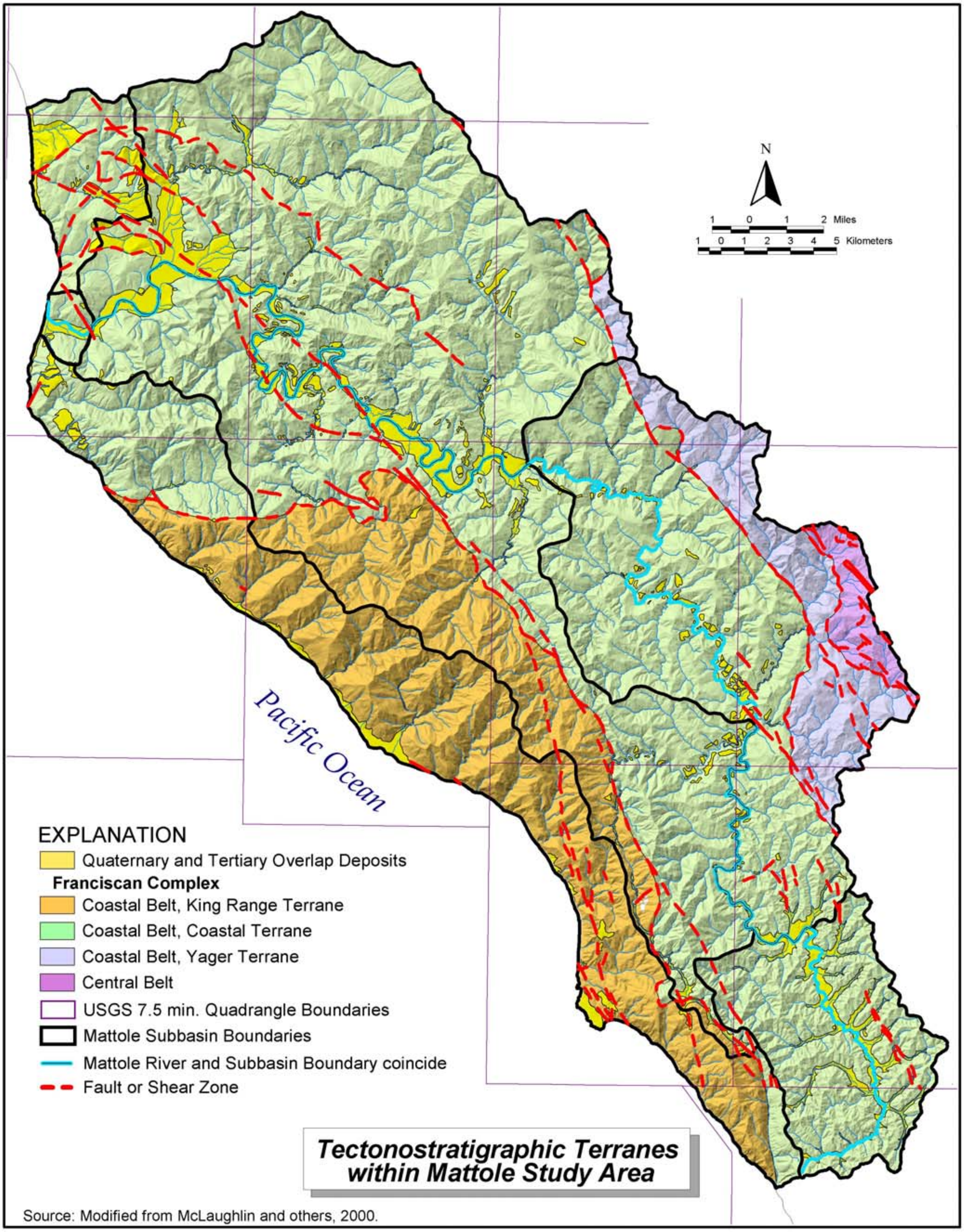

Figure 4. Tectonostratigraphic terranes within the Mattole study area.

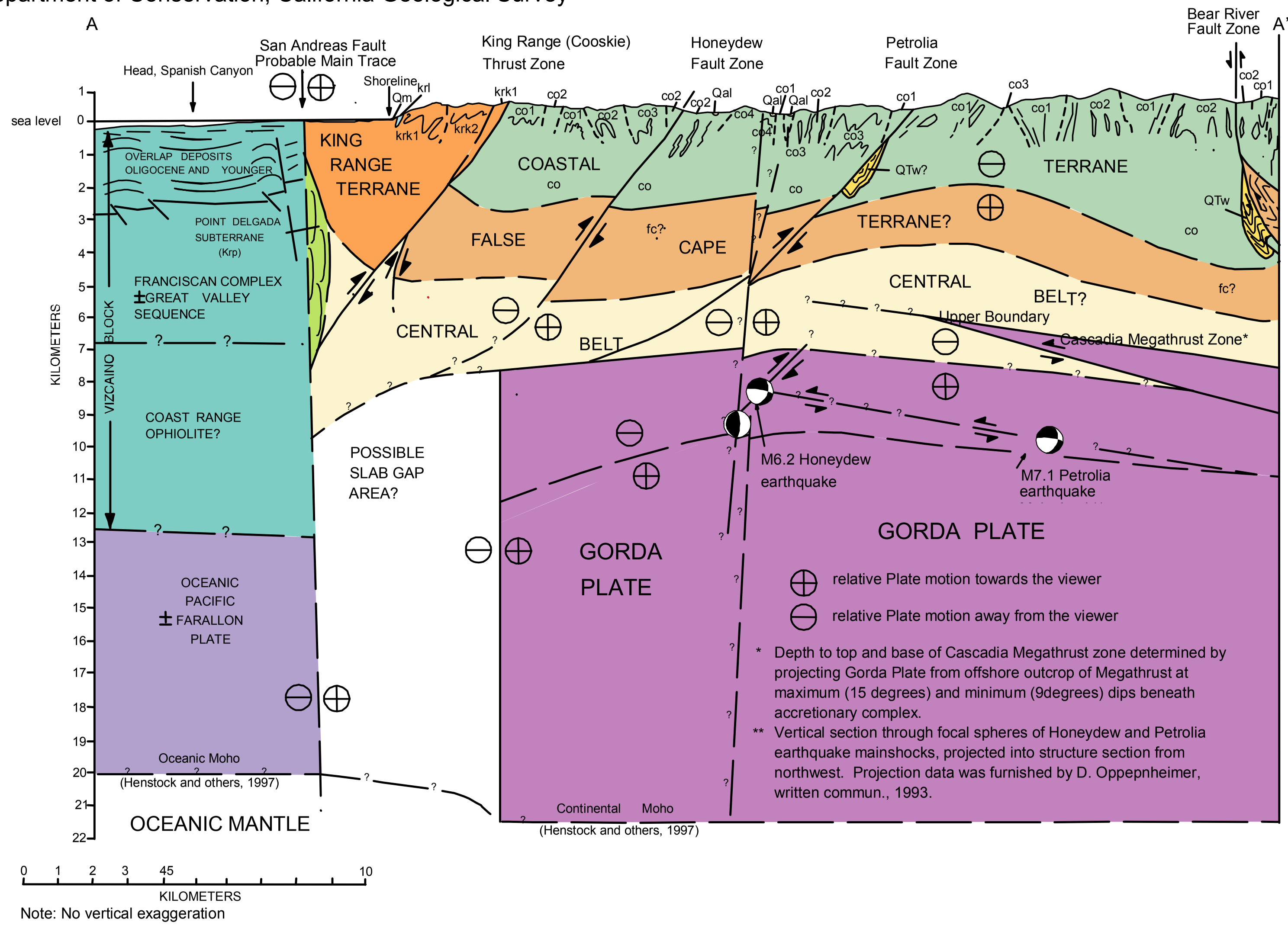

Figure 5. Geologic cross section through the Mattole study area (modified from McLaughlin and others, 2000). The location of the cross section is shown on Figure 3.

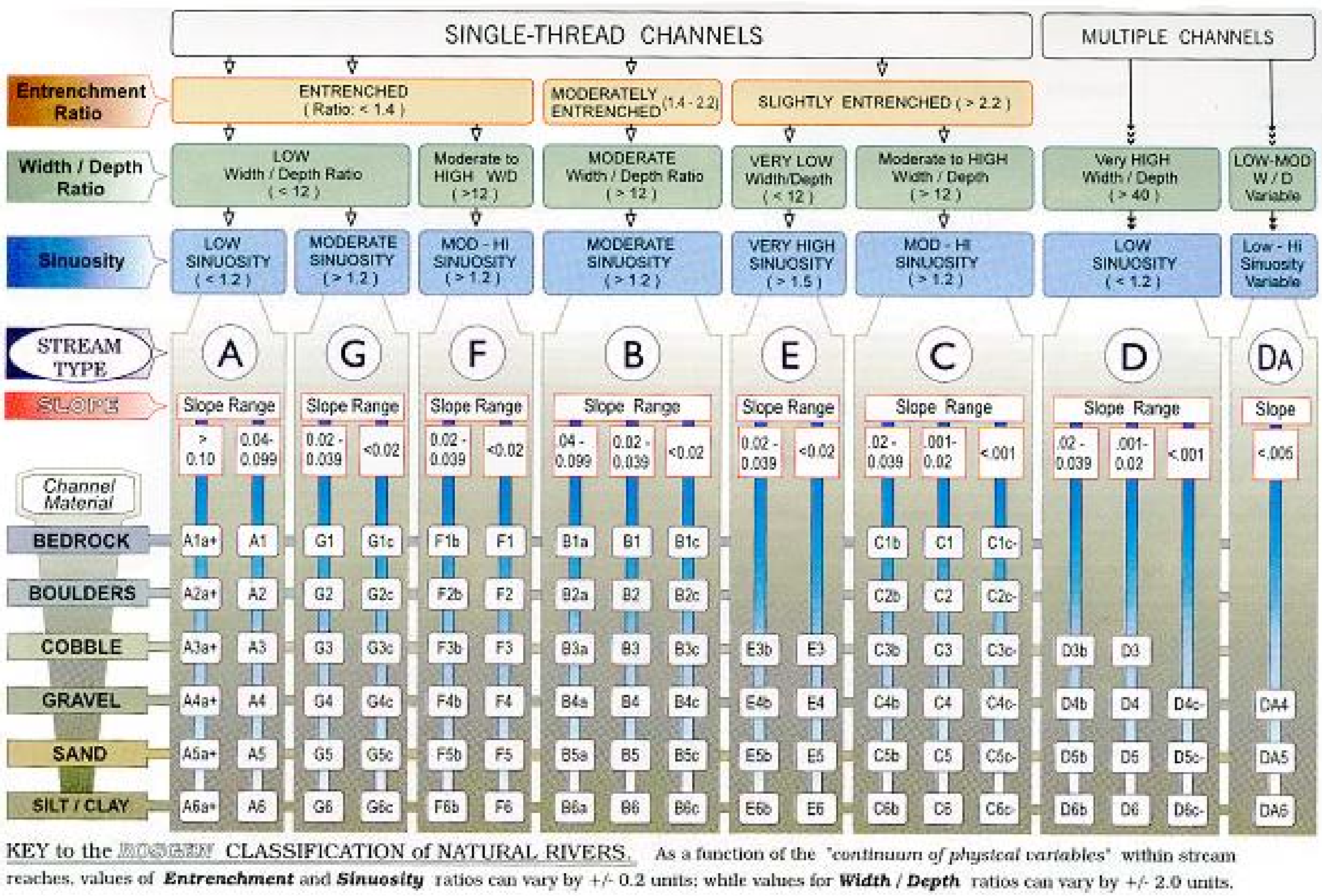

Figure 6. Rosgen stream classification system (from Rosgen, 1996).

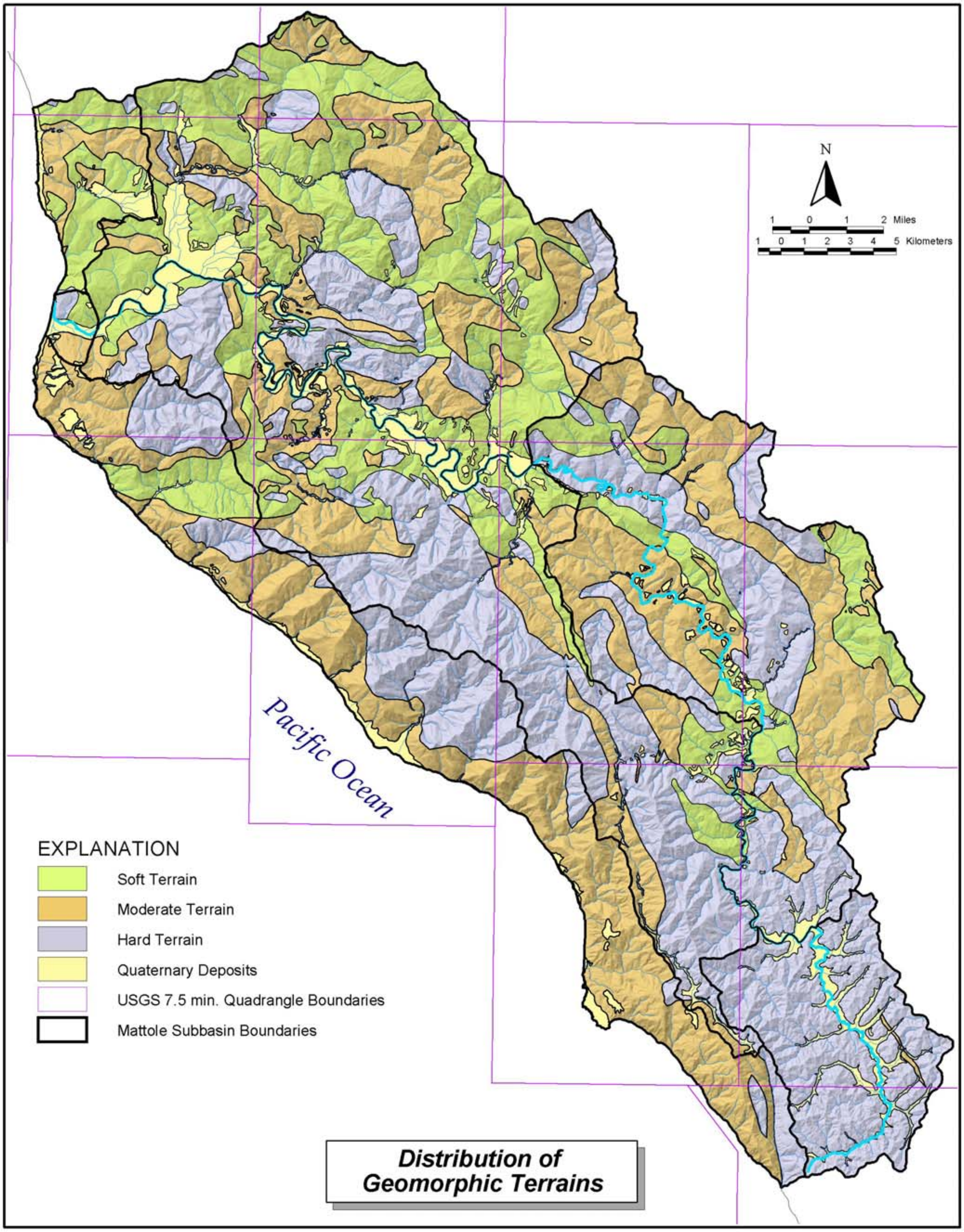

Figure 7. Distribution of Geomorphic Terrains across the study area.

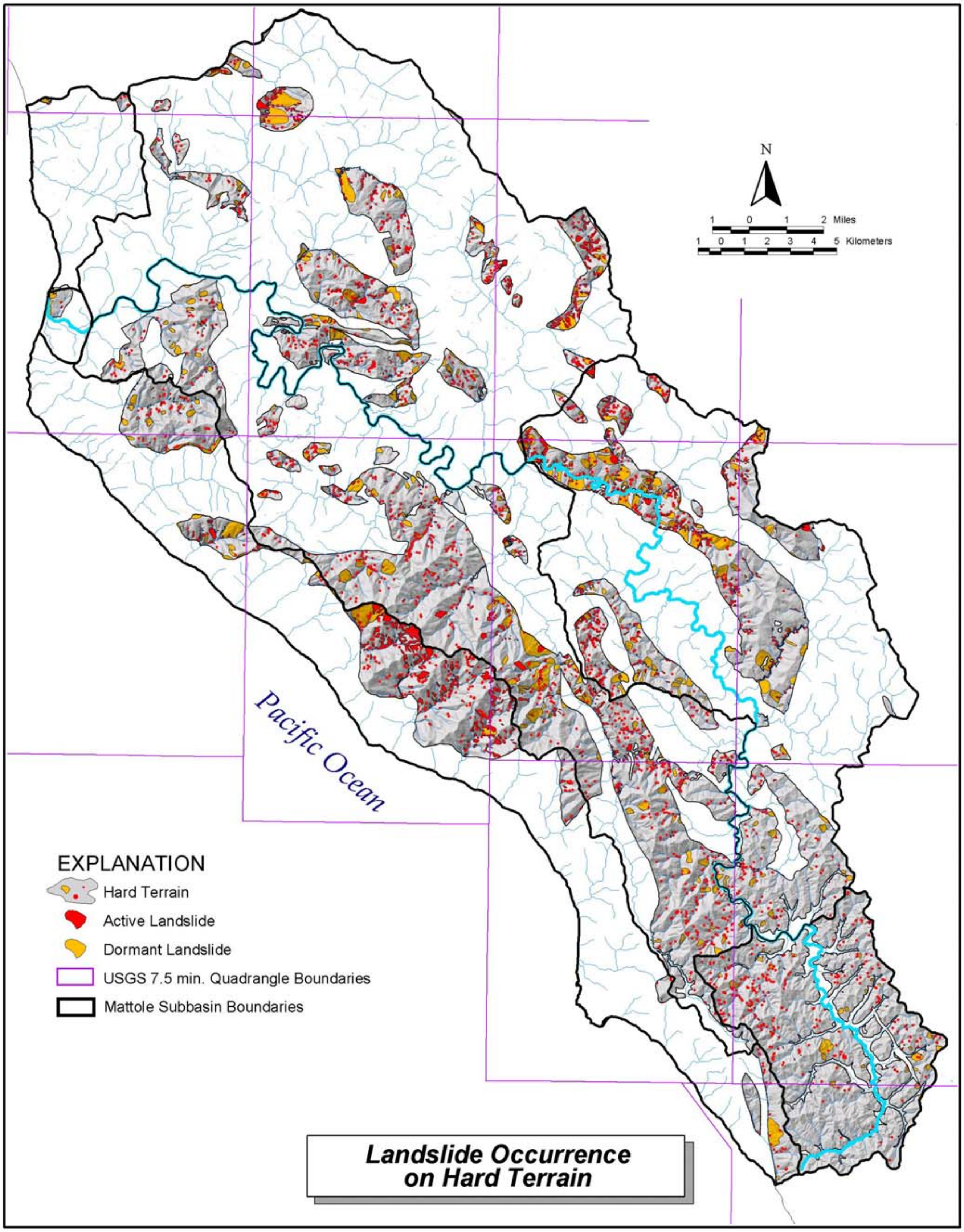

Figure 8. Occurrence of historically-active and dormant landslides on hard terrain. Dots represent slides smaller than approximately 100 feet in diameter.

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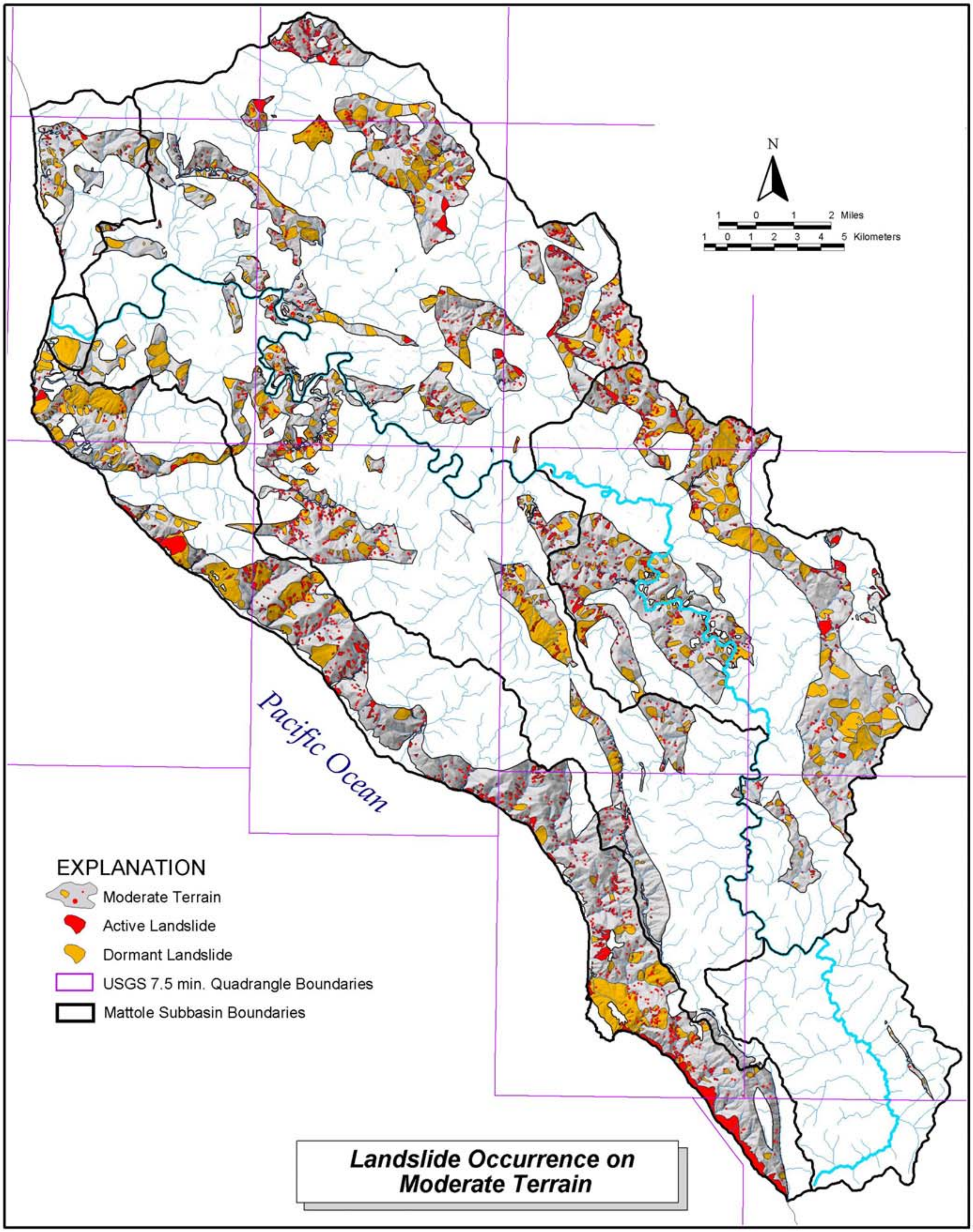


Figure 9. Occurrence of historically-active and dormant landslides on moderate terrain. Dots represent slides less than approximately 100 feet in diameter.

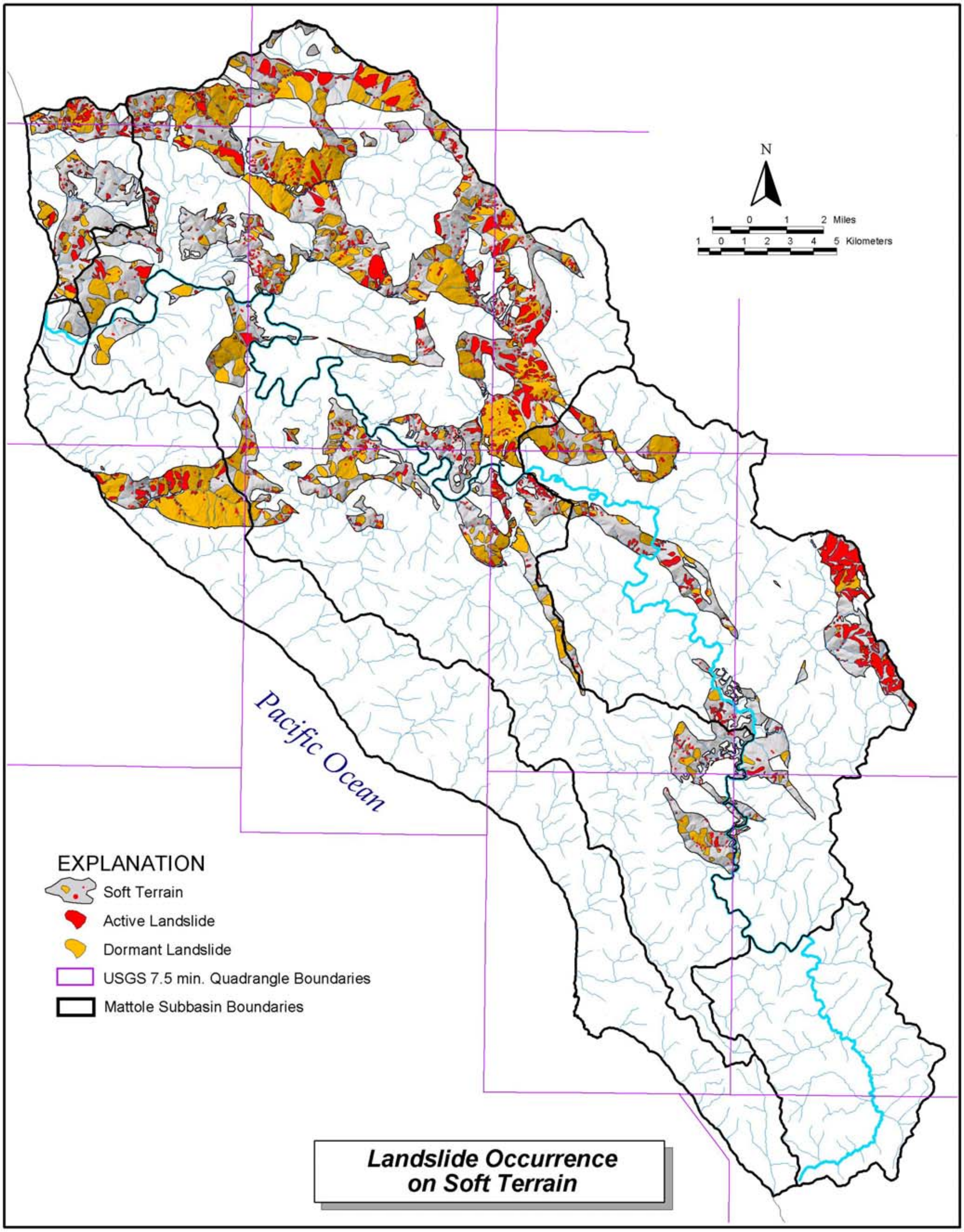


Figure 10. Occurrence of historically-active and dormant landslides on soft terrain. Dots represent slides less than approximately 100 feet in diameter.

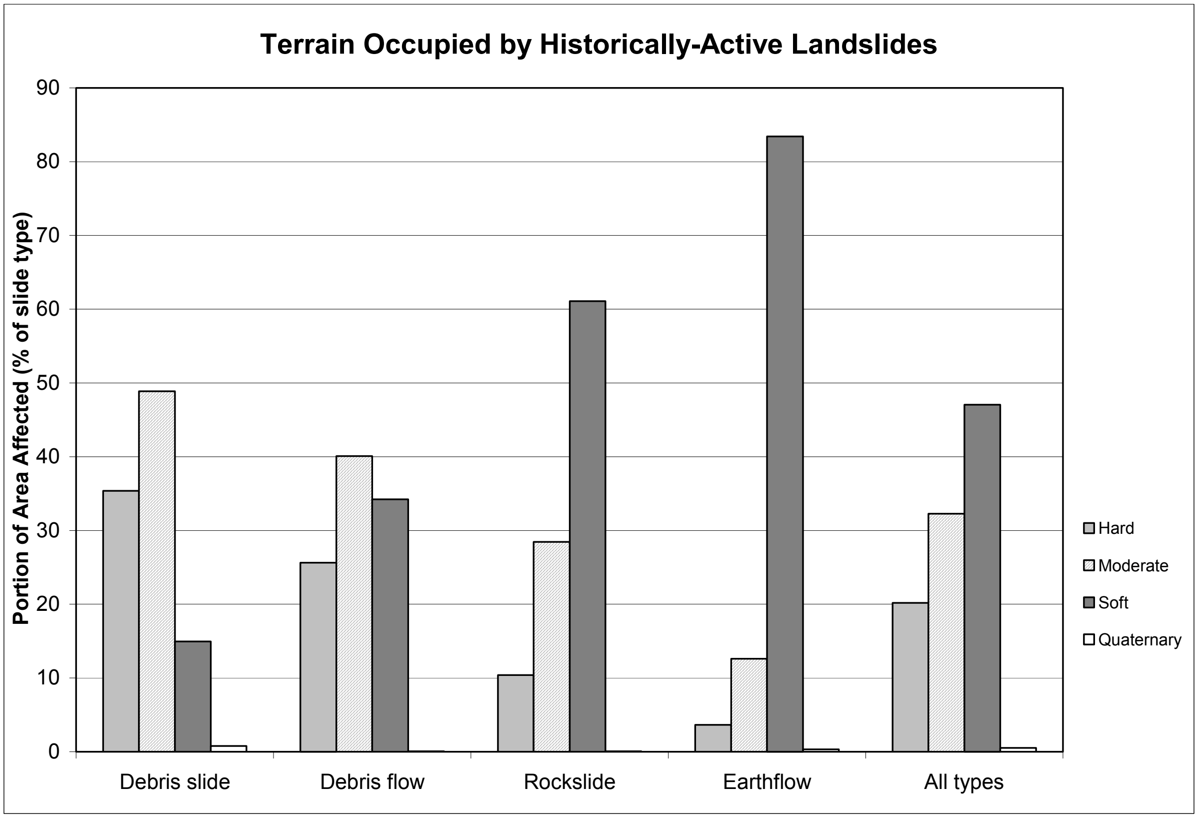


Figure 11. Percentage of area occupied by various historically-active landslide types within each geomorphic terrain.

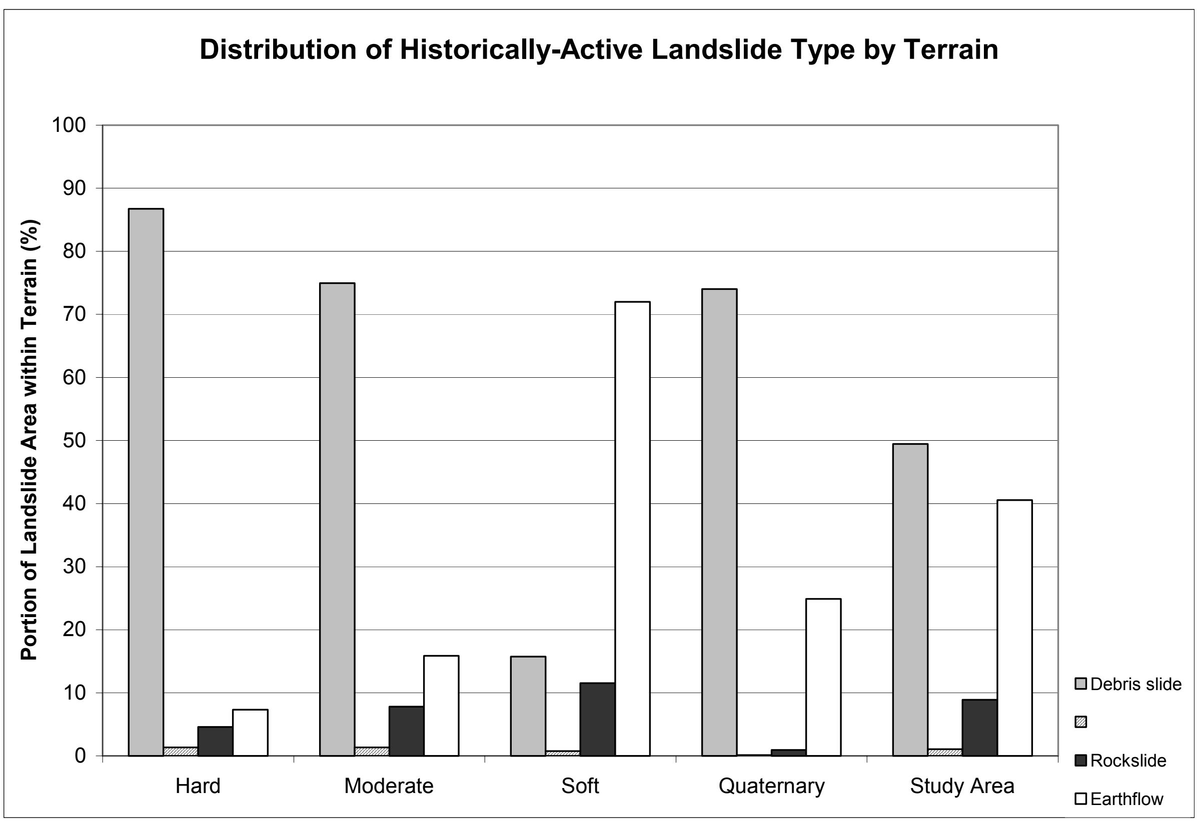


Figure 12. Distribution of landslide types within each of the geomorphic terrains.

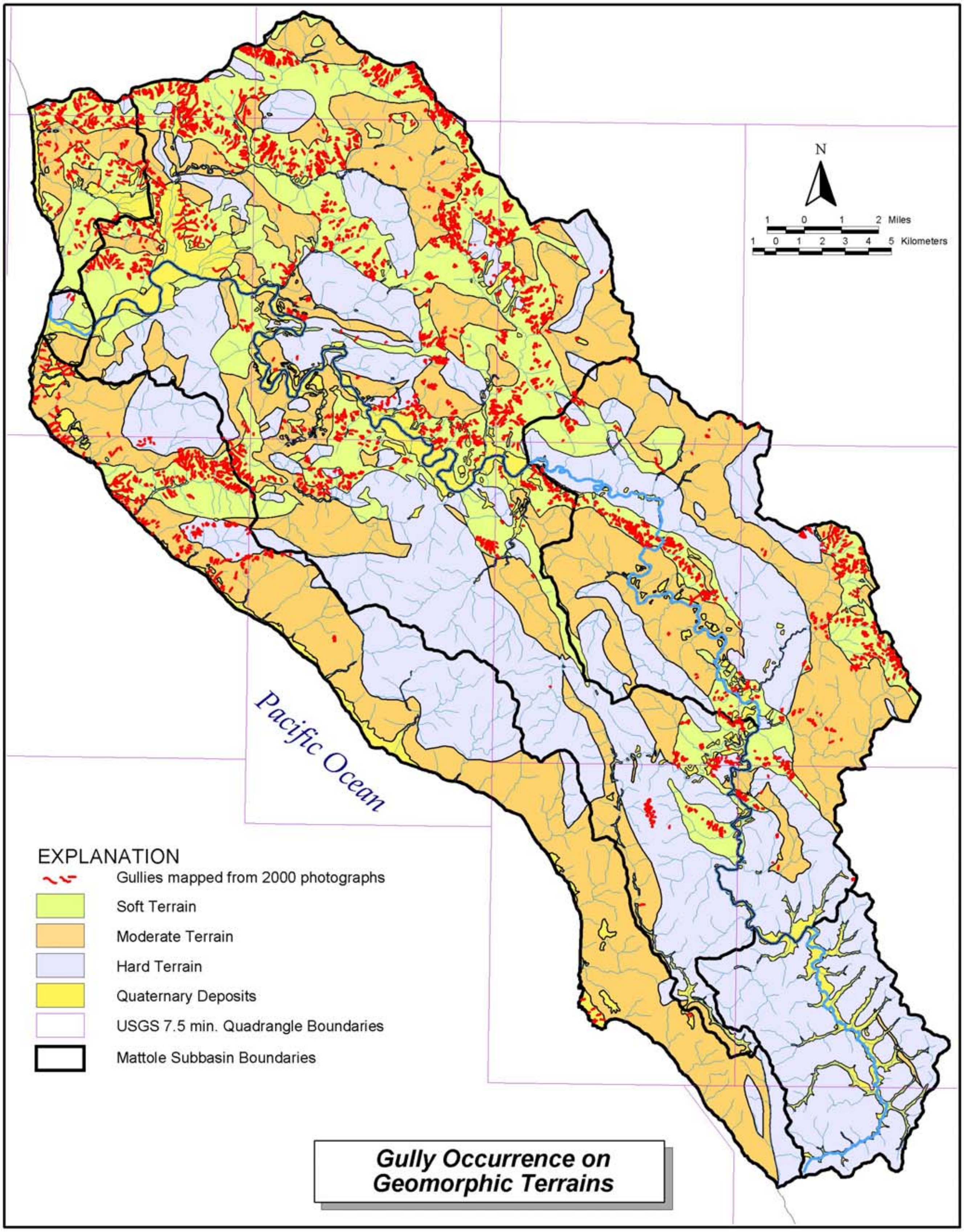


Figure 13. Distribution of gullies on geomorphic terrains.

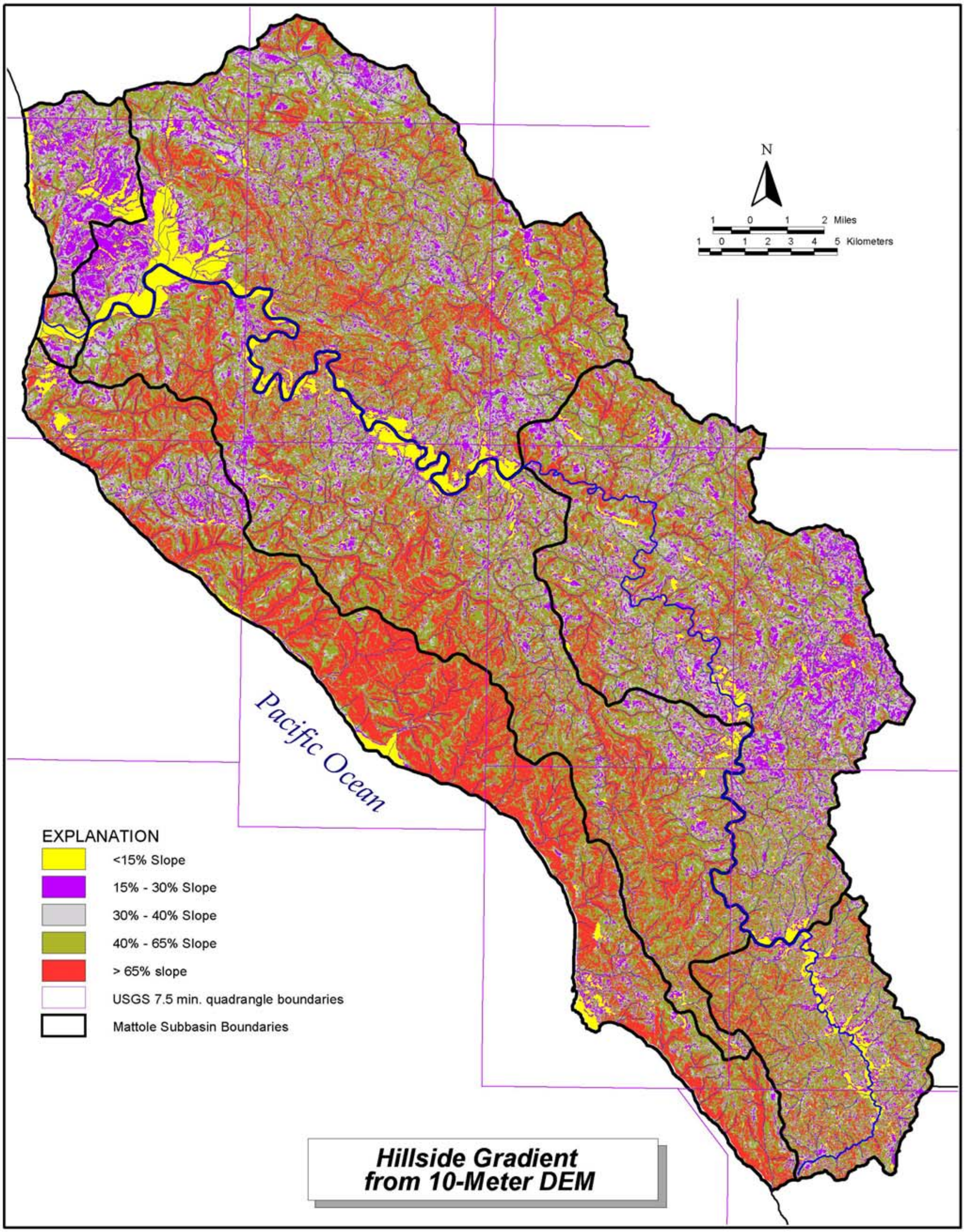


Figure 14. Map of hillside gradients developed from the 10-meter DEM.

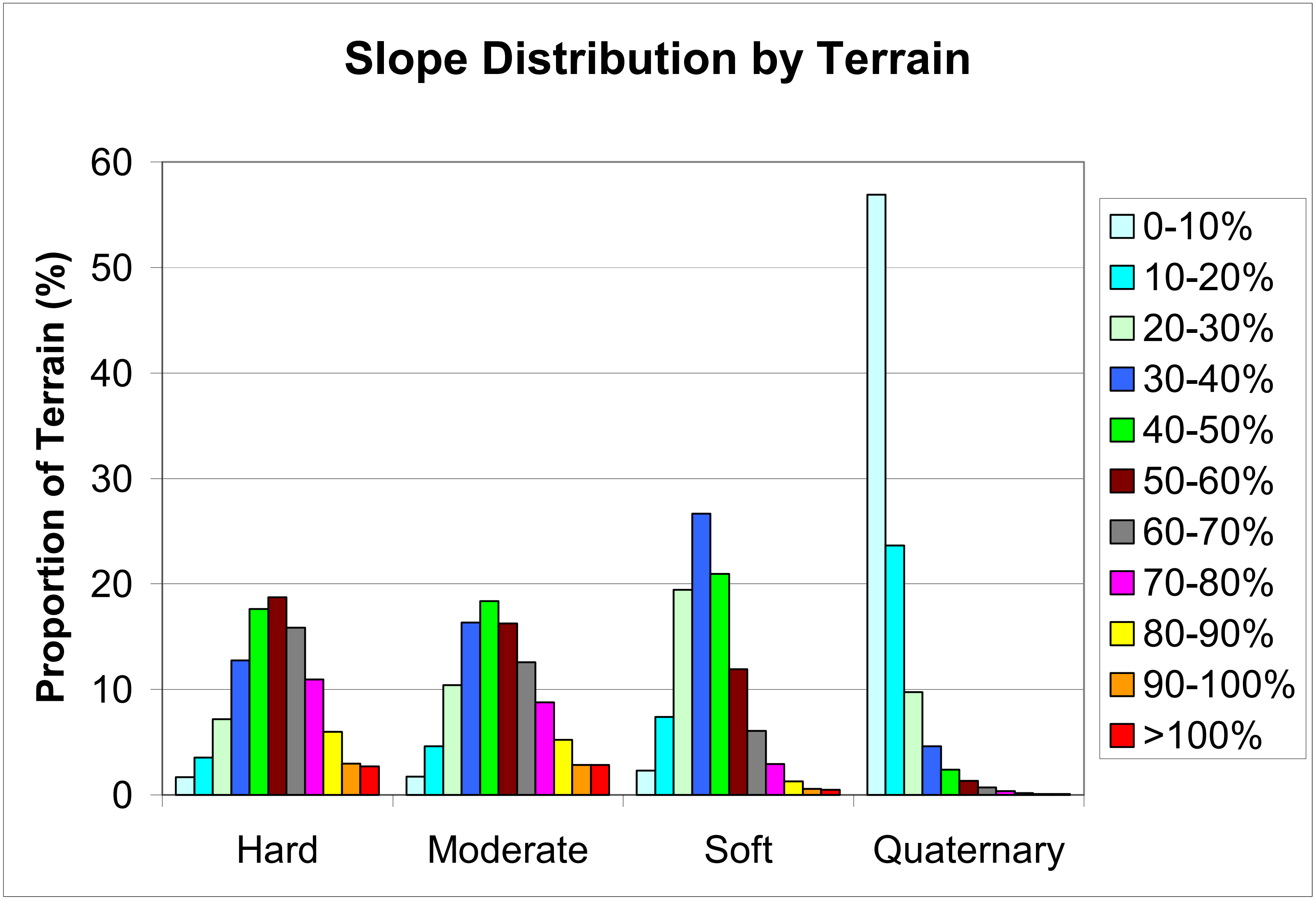


Figure 15. Histogram of slope distribution by terrain.

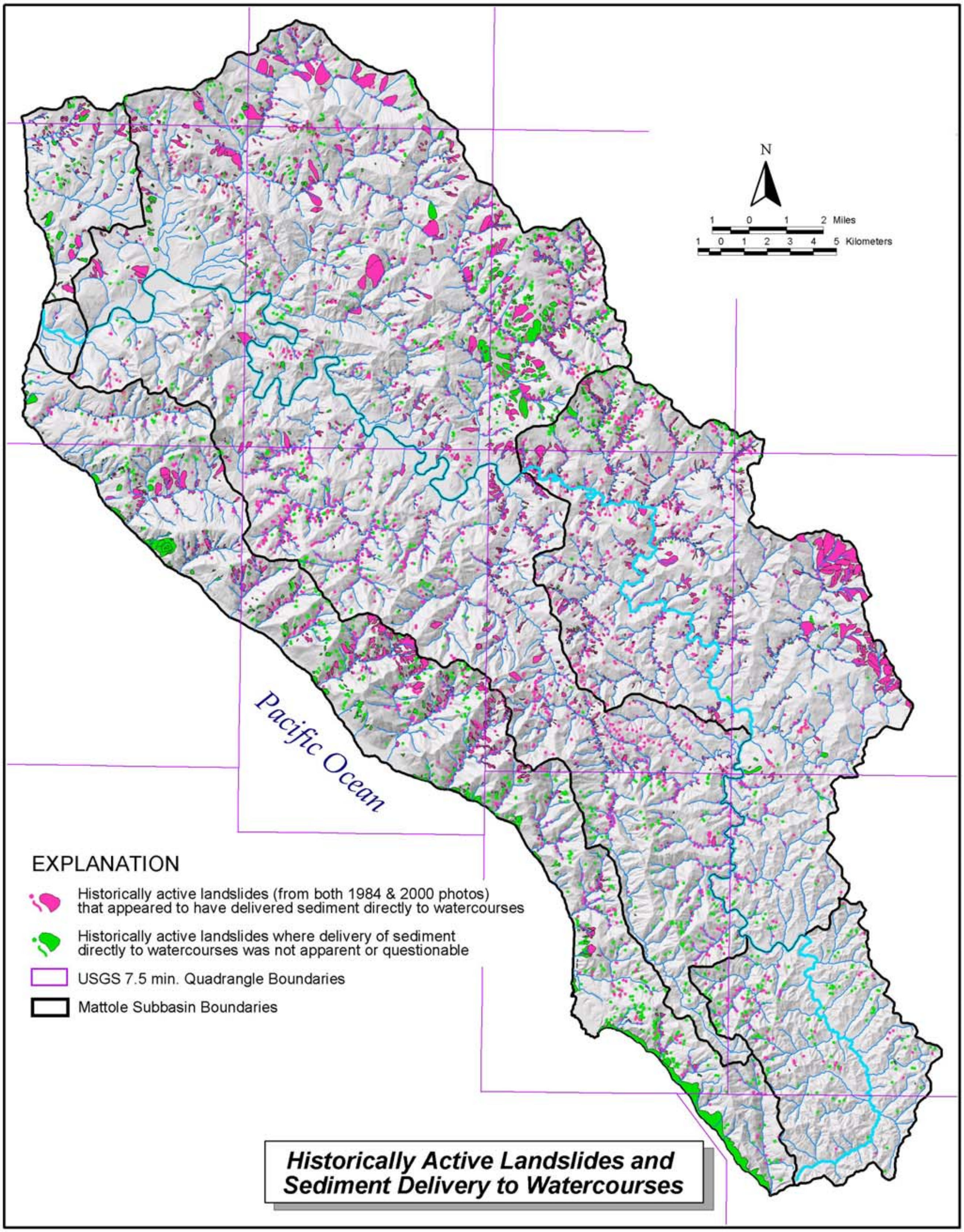


Figure 16. Overview of historically-active landslides within the Mattole study area mapped from 1984 and/or 2000 photos highlighting those landslides that appear to have delivered sediment directly to watercourses. Landslides below the minimum mapping unit for polygons of approximately 100 feet in diameter are exaggerated in size.

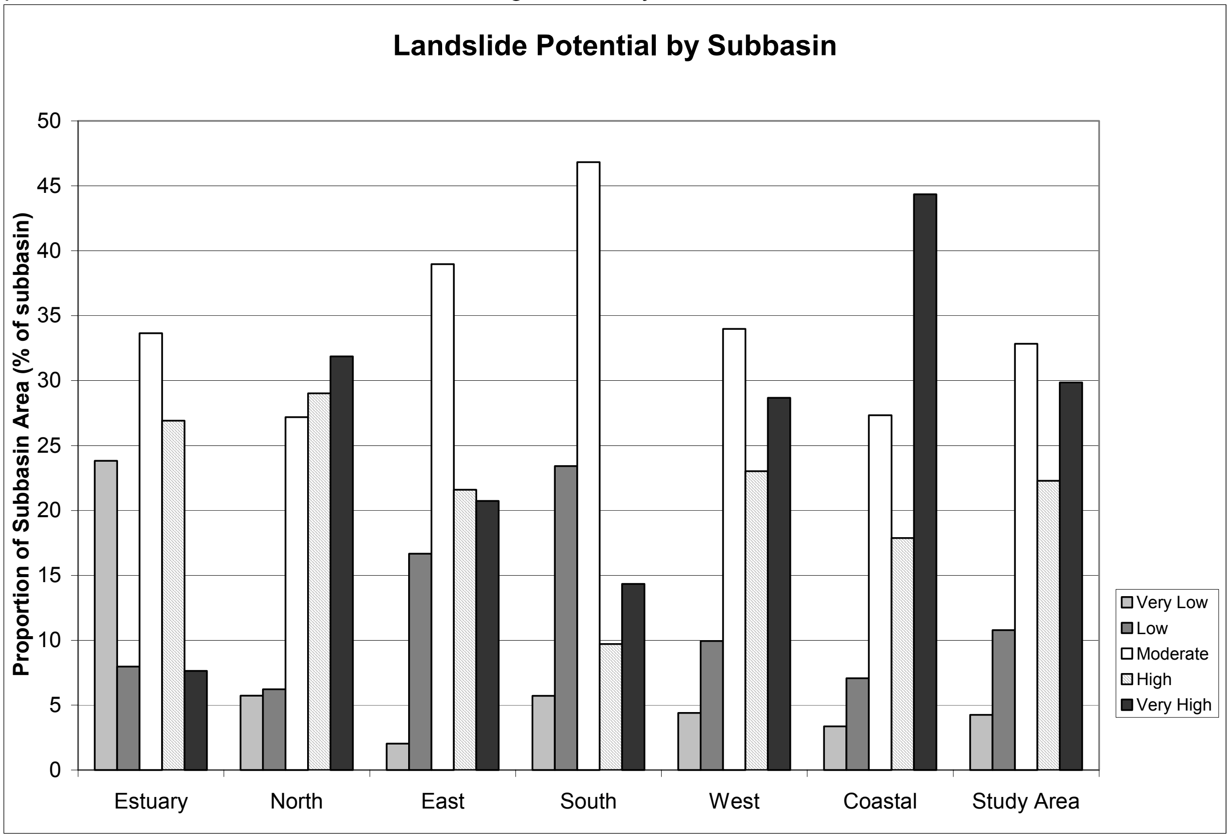


Figure 17. Proportions of each subbasin area that were assigned to the various landslide-potential categories.

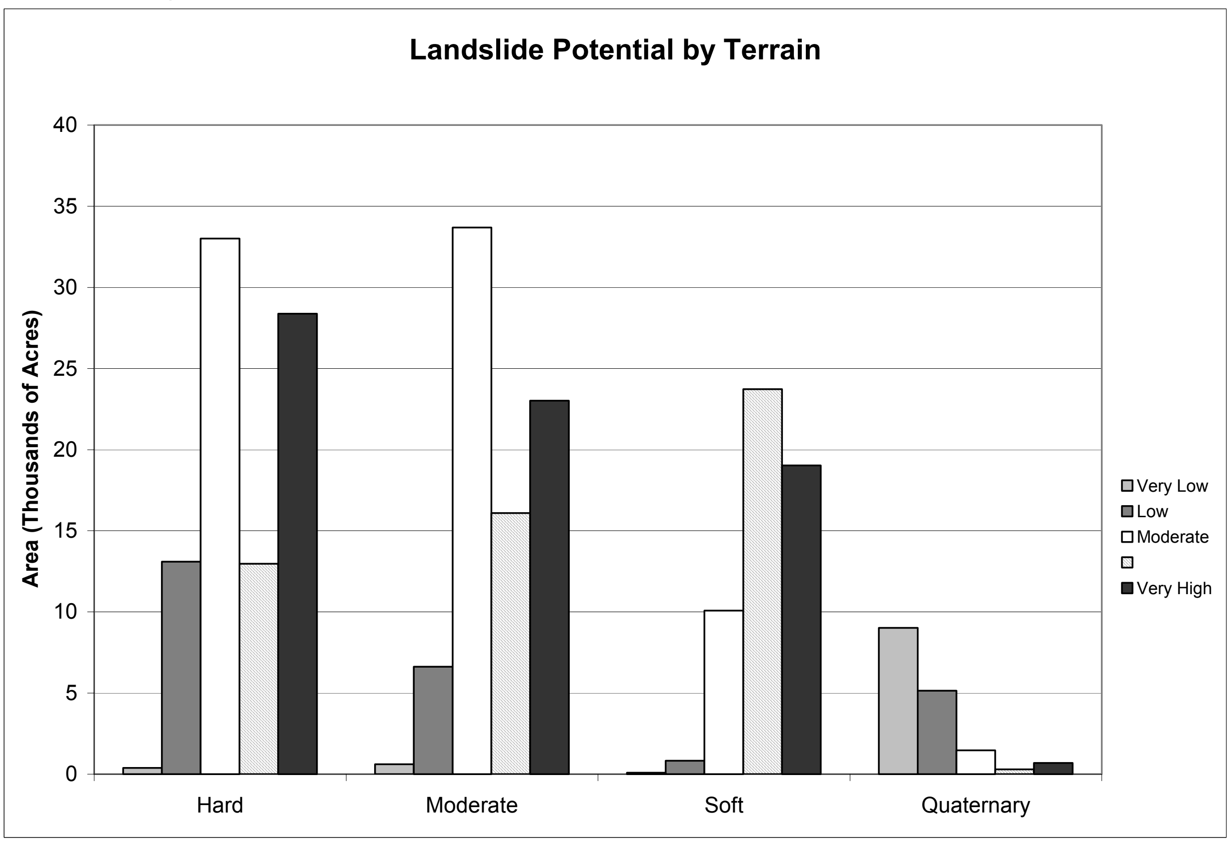


Figure 18. Area within each terrain type that was assigned to the various landslide-potential categories.

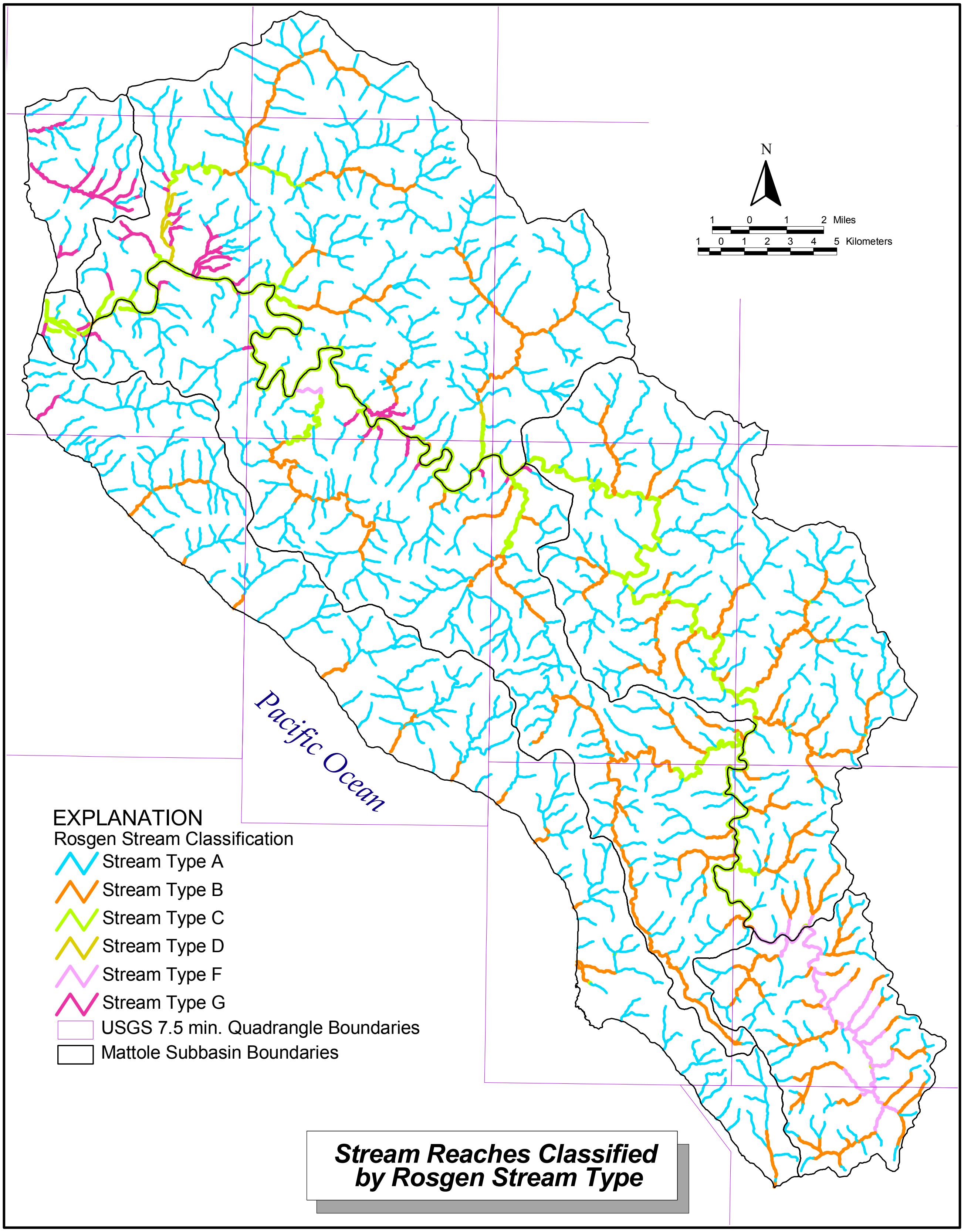


Figure 19. Distribution of stream reaches as classified by Rosgen stream type.

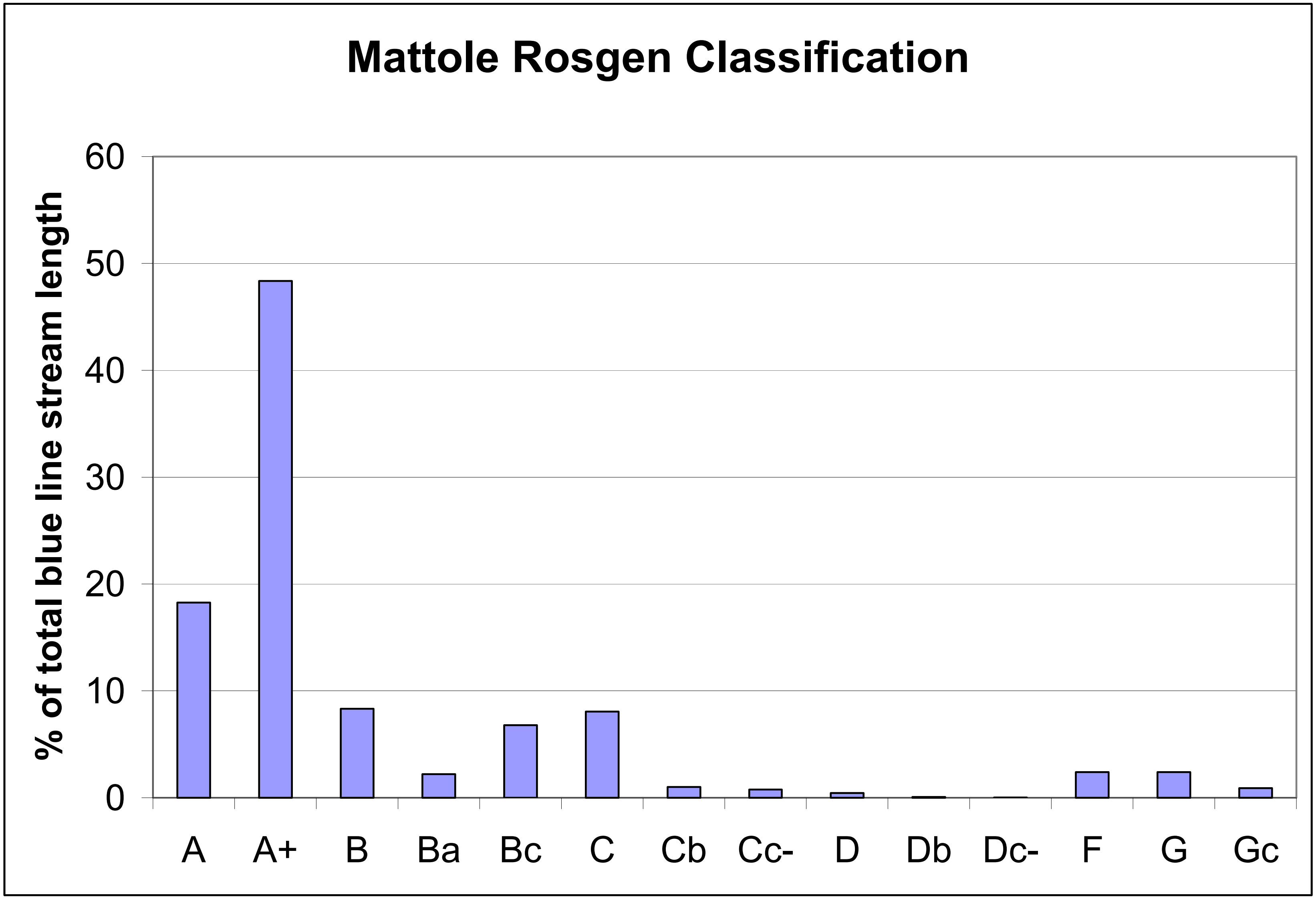


Figure 20. Histogram of Rosgen stream types as a percentage of all blue-line streams within the Mattole study area.

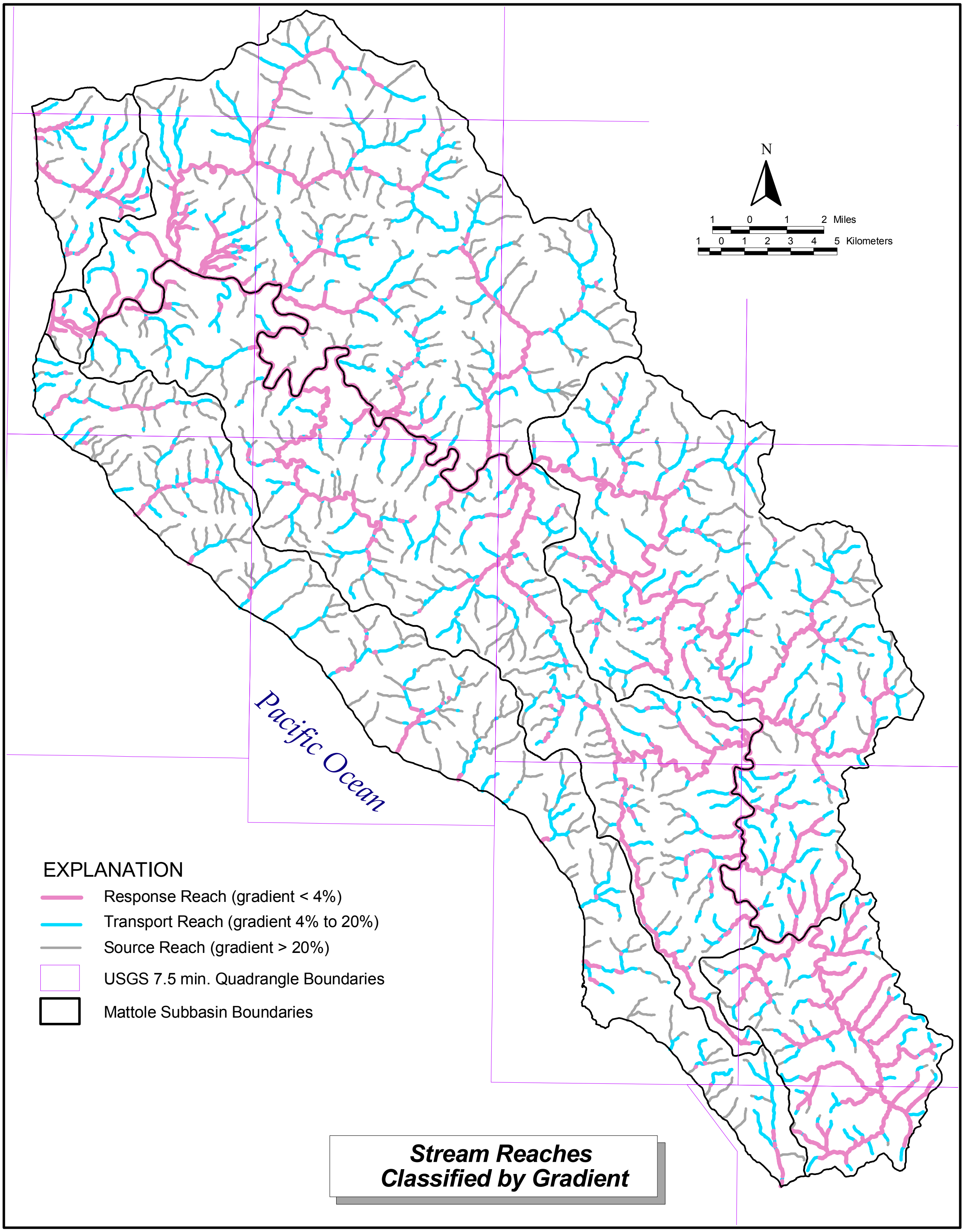


Figure 21. Distribution of blue-line stream reaches classified by gradient categories.

Figure 22. Tributary fan at Conklin Creek and mainstem Mattole River showing the effects of sediment deposition caused by a rapid transition from high gradient transport reach to low gradient response reach.

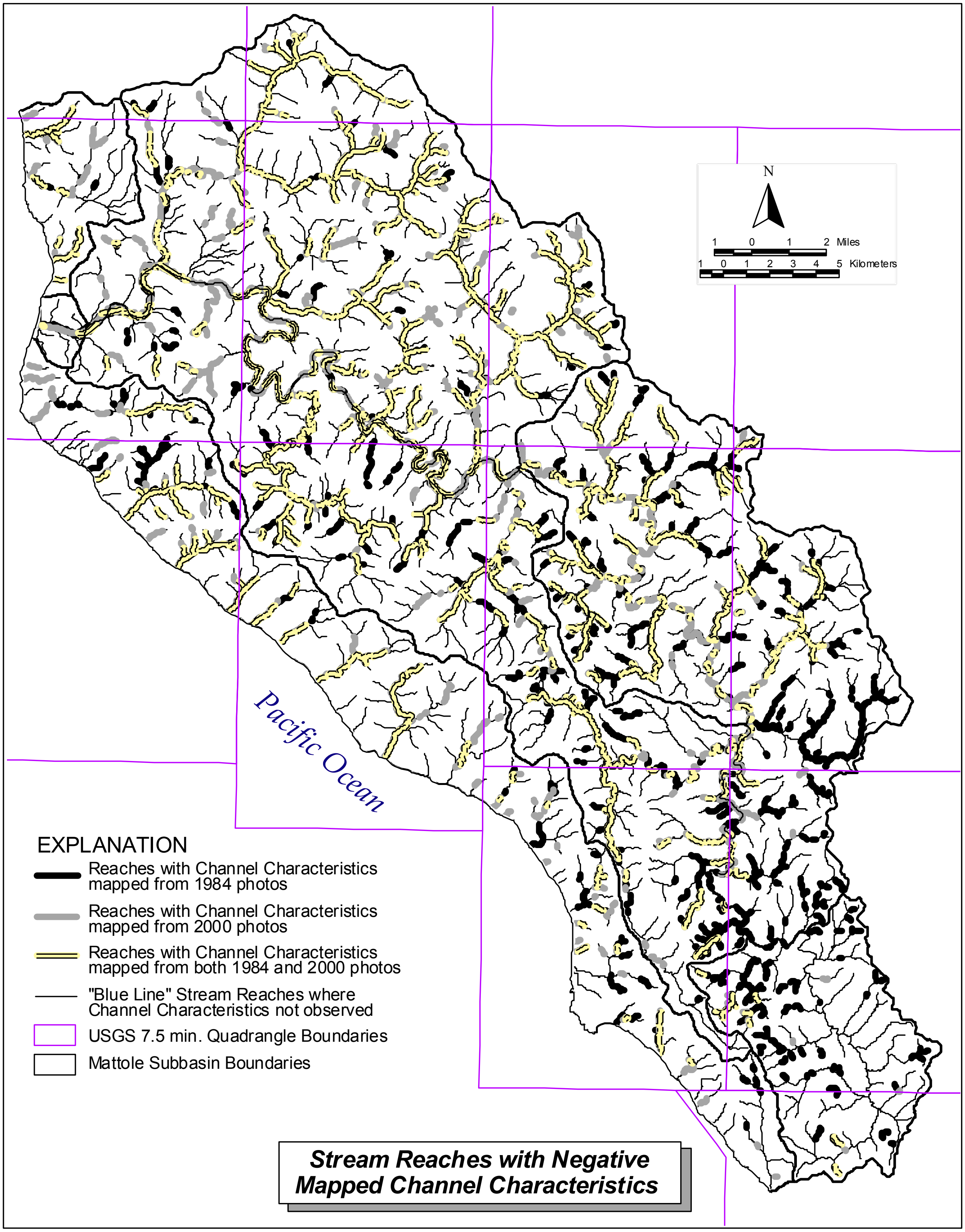


Figure 23. Compilation of mapped stream channel characteristics that may indicate excess sediment production, transport, and/or deposition. Findings indicate a general reduction in these mapped characteristics between 1984 and 2000.

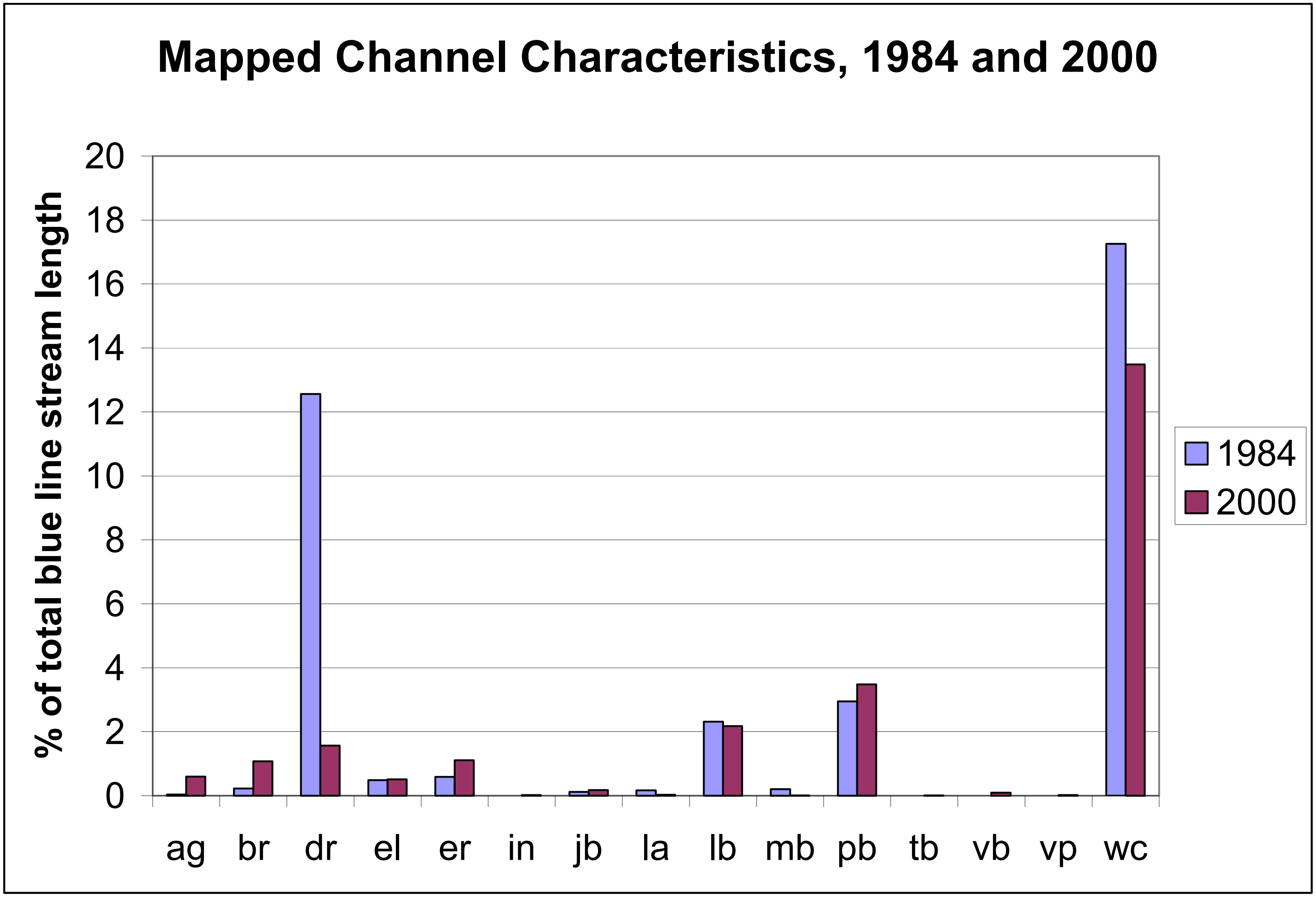


Figure 24. Percentage of all blue-line streams affected by individual primary channel characteristics mapped from 1984 and 2000 photographs (see Table 3 for explanation of channel characteristic terms).

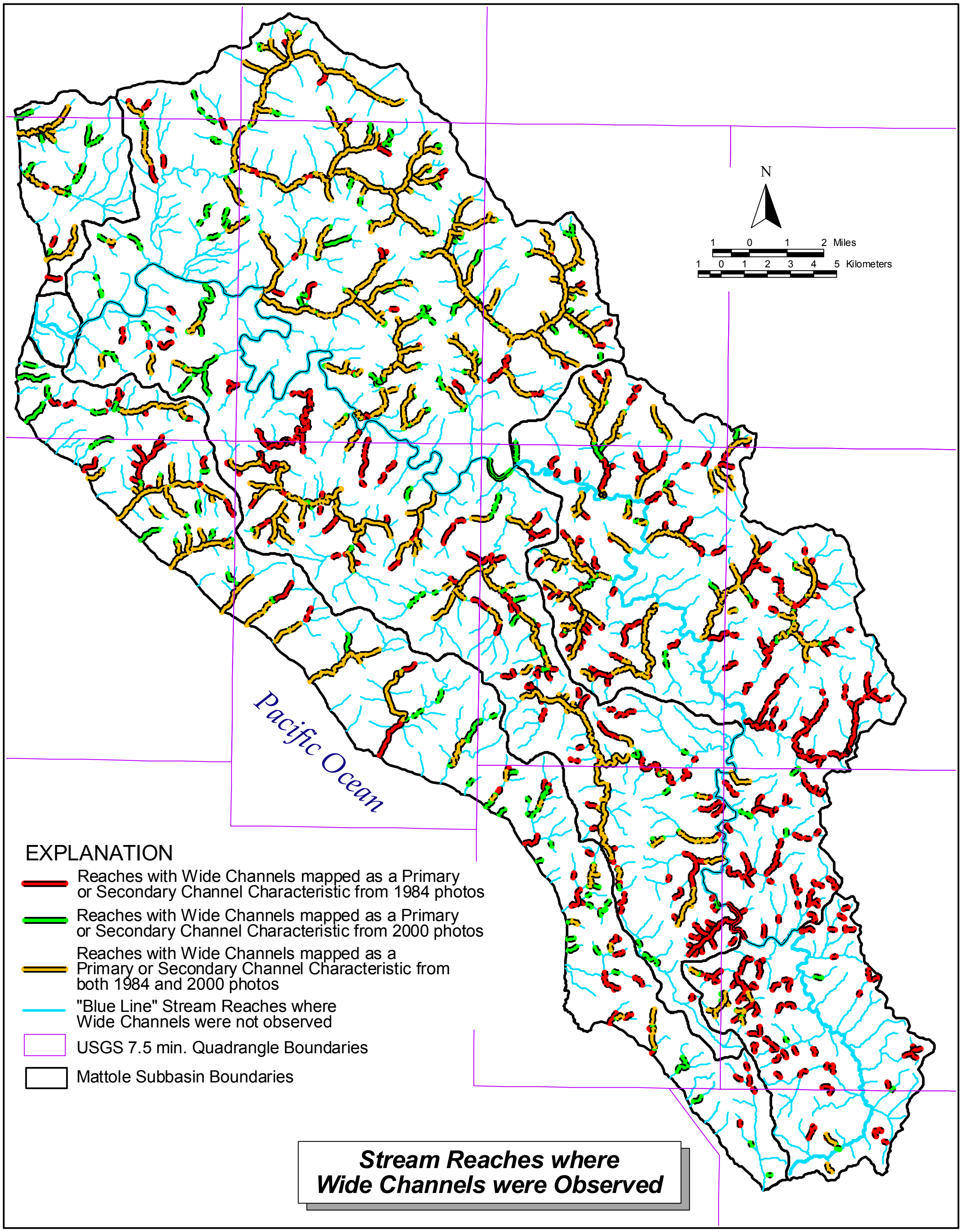


Figure 25. Stream reaches along which wide channels were mapped as either a primary or secondary channel characteristic.

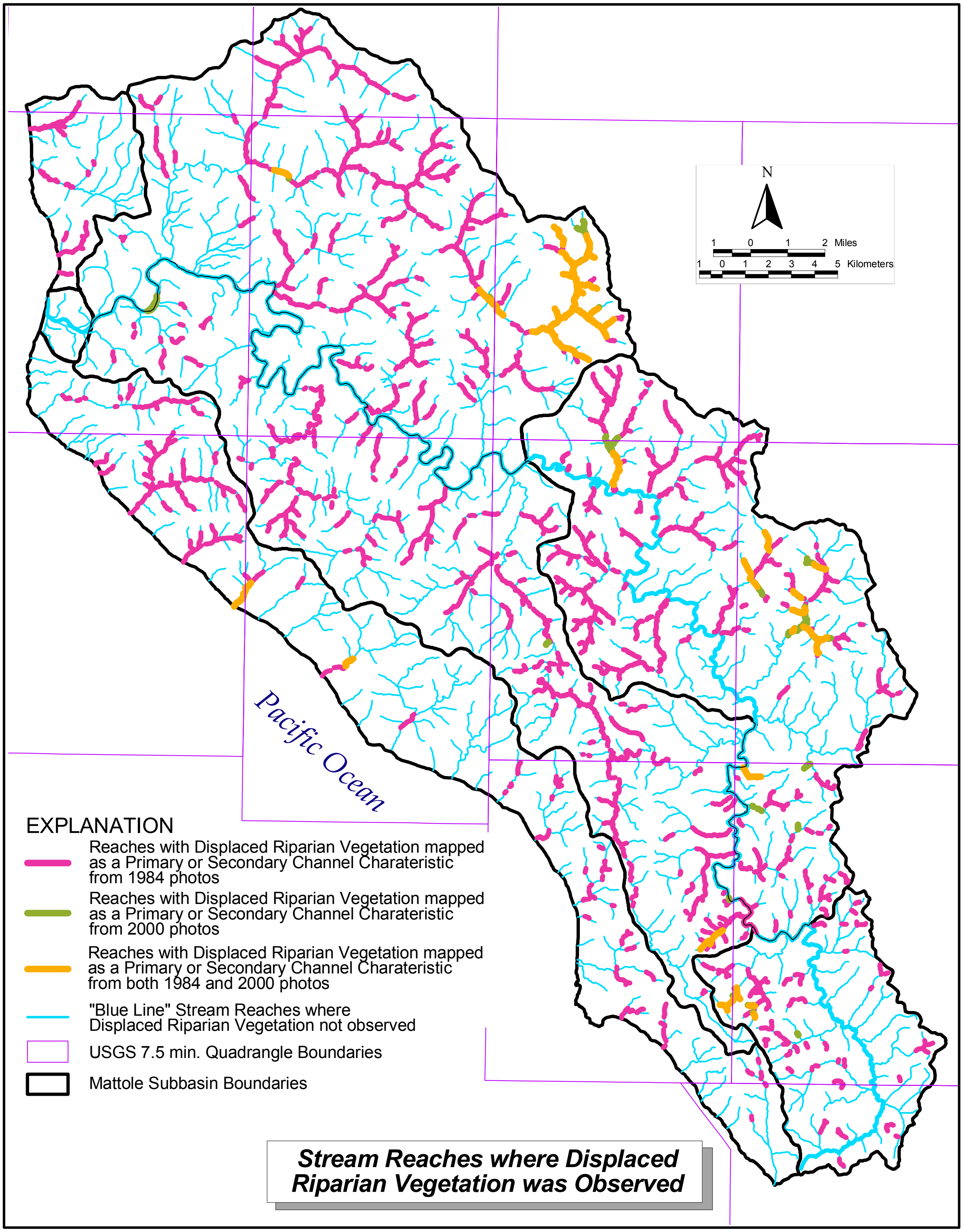


Figure 26. Stream reaches along which displaced riparian vegetation was mapped as either a primary or secondary channel characteristic.

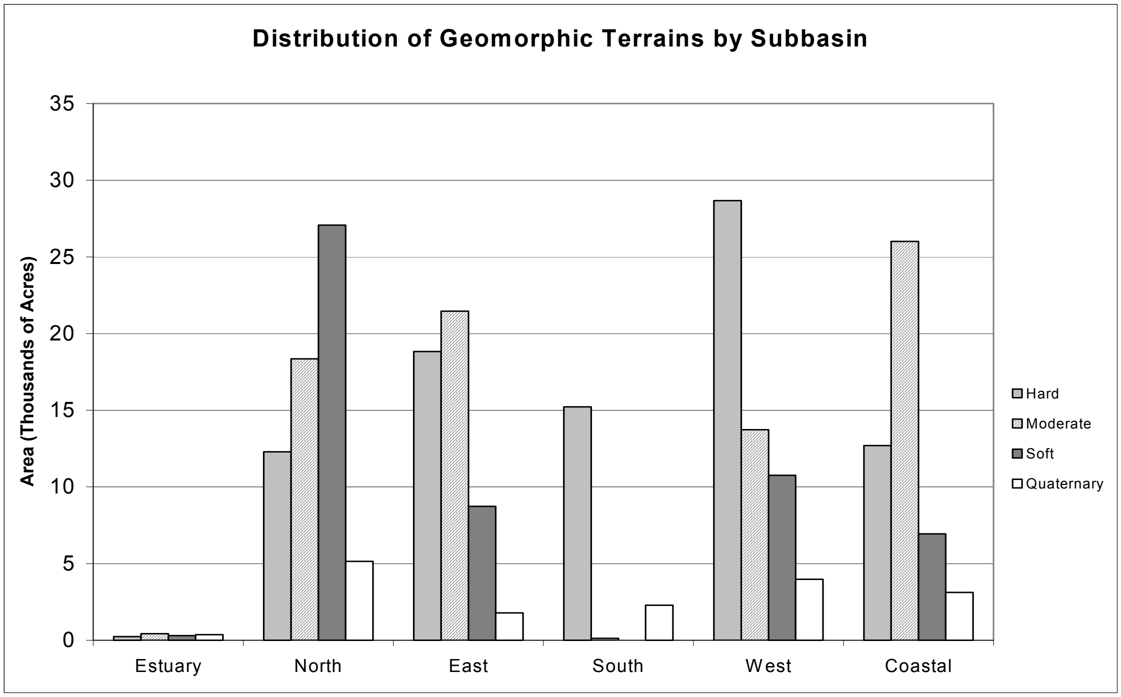


Figure 27. Area within each subbasin occupied by each of the various geomorphic terrains.

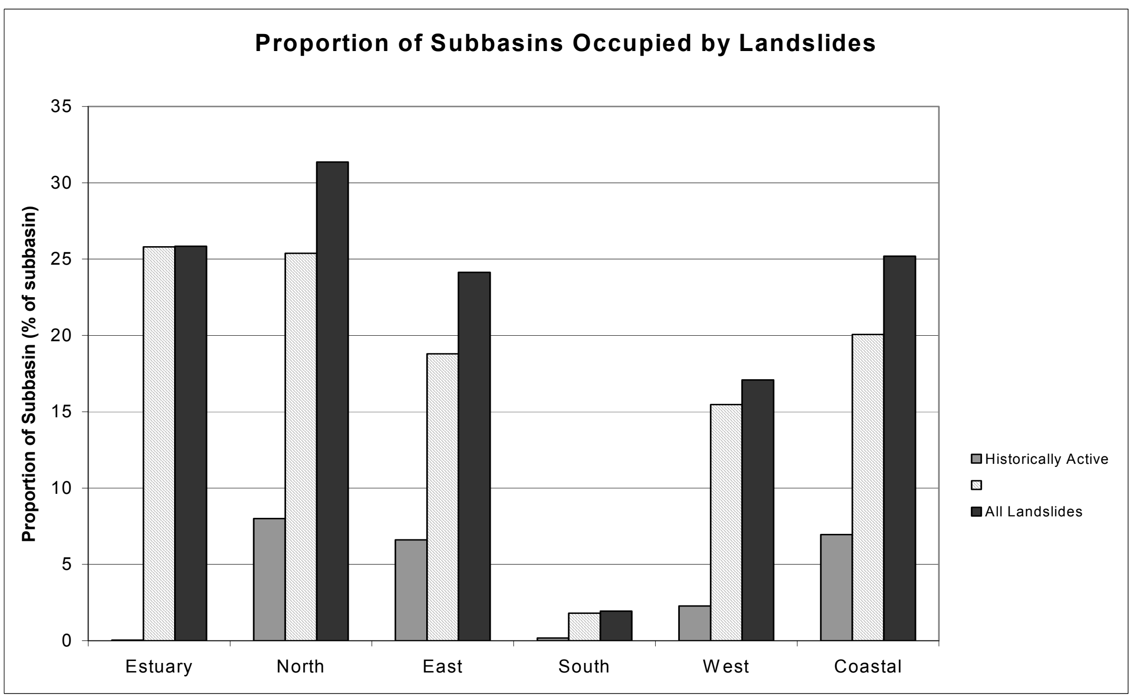


Figure 28. Percentage of each subbasin occupied by historically-active and/or dormant landslides. Those too small to delineate at map scale were assumed to have an average area of 100 square meters (approximately 1,076 square feet), and were combined with larger mappable landslides. Histogram reflects data from 1981, 1984, and 2000 photographs. Portions of dormant landslides overlain by historically-active landslides were not included in the collective totals.

TABLES

Table 1. GIS Database Structure.

Landslide Layer	Type*	Field	Content Options
Landslides (each photo year)	polygon, line, point	initial type	rock slide, debris slide, composite slide, debris flow, torrent track, earthflow
		subsequent type	rock slide, debris slide, composite slide, debris flow, torrent track, earthflow
		confidence	definite, probable, questionable
		movement mode	rotational, translational, wedge translation, compound, avalanche, flood
		activity	historically-active, dormant-young, dormant-mature, dormant-old
		observation +	stream undercut, road, timber harvest, vineyard, other agriculture, storm event, other
		age	<5 years, >5 years, uncertain
		delivery #	yes, no, uncertain
		thickness	shallow (0-10 ft), moderate (10-50 ft), thick (>50 ft)
		source	photo, field, reference, timber harvest plan, other
		remarks	text
		staff	text
Gullies (each photo year)	polygon, line	confidence	definite, probable, questionable
		age	<5 years, >5 years, uncertain
		delivery #	yes, no, uncertain
		source	photo, field, reference, timber harvest plan, other
		remarks	text
		staff	text
Irregular Slopes (single photo year)	polygon	confidence	definite, probable, questionable
		source	photo, field, reference, timber harvest plan, other
Inner Gorges (single photo year)	line	confidence	definite, probable, questionable
		source	photo, field, reference, timber harvest plan, other
Debris Slide Slopes (single photo year)	polygon	confidence	definite, probable, questionable
		source	photo, field, reference, timber harvest plan, other

Table continued on next page

Table 1. GIS Database Structure (continued).

Fluvial Layer	Type*	Field	Content Options
Alluvial Contacts (single photo year)	polygon	unit	Qmt, Qrt, Qt, Qoal, Qc, Qf, Qal, Qbs, Qds, Qscu
		remarks	text
		staff	text
Channel Classification (single photo year)	line	Rosgen, recon.	A+, A, G, Gc, Fb, F, Ba, B, Bc, Eb, E, Cb, C, Cc-, Db, D, Dc-, DA
		Rosgen, field	A+, A, G, Gc, Fb, F, Ba, B, Bc, Eb, E, Cb, C, Cc-, Db, D, Dc-, DA
		slope	value (in percent)
		sinuosity	value
		valley width	narrow, moderate, wide
		valley width, field	value
		remarks	text
		staff	text
Mapped Channel Characteristics (each photo year)	polygon, line,	primary type	aggrading reach, braided channel, displaced riparian vegetation, eroding bank, incised, junction bar, historically-active landslide deposit, lateral bar, mid-channel bar, point bar, transverse bar, vegetated bar, partially vegetated bar, wide channel
		secondary type	aggrading reach, braided channel, displaced riparian vegetation, eroding bank, incised, junction bar, historically-active landslide deposit, lateral bar, mid-channel bar, point bar, transverse bar, vegetated bar, partially vegetated bar, wide channel
		area	value
		source	photo, field, reference, timber harvest plan, other
		staff	text
Gullies (each photo year)	line	depth	value
		observation	landslide, stream undercut, road, diverted drainage, timber harvest, vineyard, storm event

Notes: Each field was not necessarily filled out for each mapped feature.
Fields and content options listed here are not comprehensive. For a comprehensive list of attributes recorded, the complete data dictionaries are reported in the metadata files associated with the GIS database.
* See text, page 18, for explanation of data type.
\+ Feature(s) listed in this field were observed in the vicinity of the landslide.
\# Sediment delivered to stream.

Table 2. Mattole Landslide Potential Matrix.

Landslide Features	Slope in percent					
	0 - 29	30 - 49	50 - 64	65+		
Historically-active slides	5	5	5	5		
Torrent/debris flow tracks	4	4	4	4		
Dormant-young rockslide	3	4	4	5		
Dormant-old or -mature rockslide	3	3	4	4		
Dormant-young earthflow	4	4	5	5		
Dormant-old or -mature earthflow	3	4	4	5		
Geomorphic Features						
Gullies	5	5	5	5		
Disrupted ground	4	4	4	4		
Debris slide slope	3	3	4	5		
Inner gorge	5	5	5	5		
SHALSTAB values <-3.1	5	5	5	5		
SHALSTAB values -3.1 to –2.8	4	4	4	4		
	Slope in percent					
Geology	0 - 10	11 - 30	31 - 40	40 – 50	51 - 64	65+
Quaternary (all Quaternary units *except QTw*)	1	2	3	3	5	5
Soft (cm1, sp, co1)	2	3	4	4	5	5
Moderate (y1, co2, krk1, QTw, other)	1	2	3	3	3	4
Hard (y2, y3, co3, co4, krk2, krk3)	1	2	2	3	3	3

Numbers reflect a relative ranking of potential movement, with 1 the lowest and 5 the highest.

Notes:

Landslide potential rankings associated with line and point features are applied to expanded “buffer” areas around the features as follows:

A buffer 15 meters (roughly 49 feet) wide is applied on each side of linear landslides, torrent tracks, and gullies.

A buffer with a radius of 25 meters (roughly 82 feet) is applied around point slides.

A buffer 25 meters (roughly 82 feet) wide is applied on each side of double-sided inner gorges.

A buffer 40 meters (roughly 131 feet) wide is applied along the downhill side of single-sided inner gorges.

Table 3. Database Dictionary for GIS: Mapped Channel Characteristics.

sed_type1 – primary* channel characteristic
sed_type2,3,4 – secondary* channel characteristic (if noted)

wc - wide channel	**ag – aggrading**
br – braided channel	**dg – degrading**
rf – riffle	**in – incised**
po – pool	ox – oxbow meander
fl – falls	ab – abandoned channel
uf – uniform flow	am – abandoned meander
tf – turbulent flow	**cc – cutoff chute**
bw – backwater	**tr – tributary fan**
pb - point bar	lj - log jam
lb - lateral bar	**ig - inner gorge**
mb – mid-channel bar	**el - eroding left bank** (facing downstream)
jb - bar at junction of channels	**er - eroding right bank** (facing downstream)
tb - transverse bar	**la - active landslide deposit**
vb - vegetated bar	**lo - older landslide deposit**
vp - partially vegetated bar	**dr – displaced riparian**
bc – blocked channel	ms – man-made structure

Note: Features in bold represent channel characteristics indicative of excess sediment in the channel.

*See text, page 23, for explanation of primary and secondary.

Table 4. Geologic Units Affected by Landsliding.

Geologic Unit	Portion of geologic unit occupied by mapped landslides (% of unit area)	Assigned Terrain*	Comment
cls	0	Moderate	limited extent
krc	0	Moderate	limited extent
krl	0	Moderate	limited extent
m	0	Moderate	limited extent
Qbs	<1	Quaternary	
Qoal	<1	Quaternary	
Qscu	<1	Quaternary	
Qal	2	Quaternary	
Qrt	3	Quaternary	
Qt	3	Quaternary	
Qf	5	Quaternary	
krb	5	Moderate	limited extent
co4	6	Hard	
Qc	8	Quaternary	
b	9	Moderate	limited extent
krk3	11	Hard	
krk2	12	Hard	
y2	12	Hard	
y3	13	Hard	
cb1	13	Moderate	limited extent
Qmt	13	Quaternary	
co3	15	Hard	
cob	18	Moderate	limited extent
QTw	19	Moderate	limited extent
krk1	22	Moderate	
Ycgl	24	Moderate	limited extent
bs	25	Moderate	limited extent
cwr	26	Moderate	limited extent
co2	29	Moderate	
y1	30	Moderate	
co1	44	Soft	
sp	48	Soft	
cm1	49	Soft	
cols	51	Moderate	limited extent
Krp	98	Moderate	limited extent

*Bedrock units of limited extent were assigned to moderate terrain. All Quaternary units were grouped together due to their expected similar overall competence.

Table 5. Distribution of Historically-Active Landslides by Geomorphic Terrain and Landslide Type.

Area Occupied by Historically-Active Landslides[1]

Landslide Type	Hard	Moderate	Soft	Quaternary	Total
Small Landslides Captured as Points[2] (Count/Acres[3])					
Debris Slide	2,537 / 251	2,392 / 236	1,232 / 122	37 / 4	6,198 / 613
Debris Flow/Torrent Track	148 / 15	160 / 16	76 / 8	1 / <1	385 / 39
Rock Slides	2 / <1	2 / <1	3 / <1	0 / 0	7 / 1
Earthflow	31 / 3	43 / 4	140 / 14	1 / <1	215 / 21
Total of small historically-active landslides	2,718 / 269	2,597 / 257	1,451 / 144	39 / 4	6,805 / 674
Larger Landslides Captured as Polygons[4] (Acres)					
Debris Slide	2,130	3,053	884	49	6,114
Debris Flow	23	43	43	0	108
Rock Slides	126	343	737	1	1,206
Earthflow	199	692	4587	18	5,495
Total of larger historically-active landslides	2,478	4,131	6,251	68	12,928
Historically-Active Small and Larger Landslides Combined (Acres)					
Combined area of historically-active landslides (all types)	2,747	4,388	6,395	72	13,602
Area underlain by each geomorphic terrain within study area[5]	87,950	80,100	53,800	16,650	238,500
Proportion of terrain area occupied by historically-active landslides	3%	6%	12%	<1%	6%
Proportion of historically-active landslide area found within each terrain	20%	32%	47%	1%	100%

[1] Includes historically-active landslides mapped from year 1981, 1984, or 2000 photographs. Landslides from year 1981 photographs are from previous mapping by Spittler (1983, 1984) covering limited portions of the watershed.

[2] Landslides smaller than approximately 100 feet in diameter were captured as points in the GIS database; larger landslides were captured as polygons.

[3] For area calculations, point landslides were assumed to have an average area of 400 square meters (roughly 1/10th acre).

[4] Where larger polygon landslides overlapped (i.e., the same or similar features mapped from more than one year of photographs) the area of overlap was counted only once.

[5] Based on Calwater 2.2a boundaries and rounding to the nearest 50 acres.

Table 6. Distribution of All Landslides by Geomorphic Terrain and Landslide Type.

Area Occupied by All (Historically-Active and Dormant) Landslides[1] (Acres)

Landslide Type	Hard	Moderate	Soft	Quaternary	Total
Debris Slide	2,008	2,599	533	50	5,190
Debris Flow/Torrent Track	33	47	34	<1	114
Rock Slides	6,804	16,216	17,247	378	40,645
Earthflow	699	2,398	6,095	53	9,245
Combined area of all landslides	9,544	21,260	23,909	481	55,194
Area underlain by each geomorphic terrain within study area[2]	87,950	80,100	53,800	16,650	238,500
Proportion of terrain area occupied by landslides	11%	26%	44%	3%	23%
Proportion of total landslide area found within each terrain	17%	39%	43%	1%	100%

[1] Includes both historically-active and dormant landslides mapped from year 1981, 1984, or 2000 photographs. Landslides from year 1981 photographs are from previous mapping by Spittler (1983, 1984) covering limited portions of the watershed. Landslides smaller than approximately 100 feet in diameter were captured as points in the GIS database; larger landslides were captured as polygons. For area calculations, point landslides were assumed to have an average area of 400 square meters (roughly 1/10th acre). Where landslides overlapped (i.e., historically-active landslides over dormant landslides and/or similar features mapped from more than one year of photographs) the area of overlap was only counted once.

[2] Based on Calwater 2.2a boundaries and rounding to the nearest 50 acres.

Table 7. Distribution of Historically-Active Landslides by Subbasin and Geomorphic Terrain.

Area Occupied by Historically-Active Landslides[1]

Terrain	Estuary	North	East	South	West	Coastal
Small Landslides Captured as Points[2] (Count/Acres[3])						
Hard	2 / <1	562 / 56	656 / 65	269 / 27	866 / 86	358 / 35
Moderate	0 / 0	766 / 76	605 / 60	3 / <1	526 / 52	696 / 69
Soft	0 / 0	903 / 89	147 / 15	0 / 0	296 / 29	108 / 11
Quaternary	0 / 0	10 / 1	15 / 1	3 / <1	13 / 1	1/<1
Total of Small Historically-Active Landslides	2 / <1	2,241/222	1,423/141	275/27	1,701/168	1,163/115
Larger Landslides Captured as Polygons[4] (Acres)						
Hard	<1	532	709	23	425	791
Moderate	0	1,081	972	2	310	1,771
Soft	0	3,331	1,608	0	514	799
Quaternary	0	23	33	0	8	3
Total Area of Larger Historically-Active Landslides	<1	4,967	3,322	25	1,257	3,364
Historically-Active Small and Large Landslides Combined (Acres)						
Combined area of all historically-active landslides (all terrains)	<1	5,189	3,463	52	1,425	3,479
Area of each subbasin[5]	1,300	62,850	50,800	17,650	57,150	48,750
Proportion of total subbasin area occupied by historically-active landslides	<1%	8%	7%	<1	2%	7%
Proportion of total landslide area within each subbasin	<1%	38%	25%	<1%	10%	26%

[1] Includes historically-active landslides mapped from year 1981, 1984, or 2000 photographs. Landslides from year 1981 photographs are from previous mapping by Spittler (1983, 1984) covering limited portions of the watershed.

[2] Landslides smaller than approximately 100 feet in diameter were captured as points in the GIS database; larger landslides were captured as polygons.

[3] For area calculations, point landslides were assumed to have an average area of 400 square meters (roughly 1/10th acre).

[4] Where larger polygon landslides overlapped (i.e., the same or similar features mapped from more than one year of photographs) the area of overlap was counted only once.

[5] Based on Calwater 2.2a boundaries and rounding to the nearest 50 acres.

Table 8. Distribution of All Landslides by Subbasin and Geomorphic Terrain.

Area Occupied by All (Historically-Active and Dormant) Landslides[1] (Acres)

Terrain	Estuary	North	East	South	West	Coastal
Hard	35	2,131	2,941	348	2,413	1,680
Moderate	261	4,743	5,865	13	3,456	6,927
Soft	32	12,883	3,448	0	3,954	3,593
Quaternary	13	101	104	7	78	178
Combined area of all historically-active and dormant landslides	341	19,858	12,358	368	9,901	12,378
Area of Subbasin	1,300	62,850	50,800	17,650	5,7150	4,8750
Proportion of subbasin occupied by landslides	26%	32%	24%	2%	17%	25%
Proportion of total landslide area found in each subbasin	1%	36%	22%	1%	18%	22%

[1] Includes both historically-active and dormant landslides mapped from year 1981, 1984, or 2000 photographs. Landslides from year 1981 photographs are from previous mapping by Spittler (1983, 1984) covering limited portions of the watershed. Landslides smaller than approximately 100 feet in diameter were captured as points in the GIS database; larger landslides were captured as polygons. For area calculations, point landslides were assumed to have an average area of 400 square meters (roughly 1/10th acre). Where landslides overlapped (i.e., historically-active landslides over dormant landslides and/or similar features mapped from more than one year of photographs) the area of overlap was only counted once.

[2] Based on Calwater 2.2a boundaries and rounding to the nearest 50 acres.

Table 9. Inner Gorges.

Subbasin	Terrain	All Mapped Inner Gorges			Inner Gorges along Blue-Line Streams			Contrast All Mapped Inner Gorges against Inner Gorges along Blue-Line Streams	
		Length (miles)	% of Total Subbasin Inner Gorge Length	% of Total Study Area Inner Gorge Length	Length along Blue-Line Streams (miles)	% of Total Subbasin Inner Gorge Length	% of Total Study Area Inner Gorge Length	% of total Blue-Line Stream Length with Inner Gorge [2]	Difference Between Total Inner Gorge Length and Inner Gorge length only along Blue-Line Streams [1]
Estuary	Hard [3]	0.0	0	0	0.0	0	0	0	0
	Moderate	0.0	0	0	0.0	0	0	0	0
	Soft [3]	0.0	0	0	0.0	0	0	0	0
	Alluvium	0.0	0	0	0.0	0	0	0	0
Northern	Hard	29.6	31	9	22.4	31	8	56	-24
	Moderate	34.0	35	10	25.4	35	9	49	-25
	Soft	32.2	34	10	24.9	34	9	34	-23
	Alluvium	0.0	0	0	0.0	0	0	0	0
Subbasin Total		95.7	100	29	72.7	100	27	34	-24
Eastern	Hard	39.1	53	12	31.2	51	11	53	-20
	Moderate	27.9	38	8	24.7	40	9	37	-12
	Soft	6.7	9	2	5.7	9	2	23	-15
	Alluvium	0.0	0	0	0.0	0	0	0	0
Subbasin Total		73.7	100	22	61.6	100	23	33	-16
Southern	Hard	27.3	99	8	17.6	99	6	58	-36
	Moderate	0.1	1	0	0.1	1	0.05	78	0
	Soft	0.0	0	0	0.0	0	0	0	0
	Alluvium	0.0	0	0	0.0	0	0	0	0
Subbasin Total		27.4	100	8	17.7	100	6	26	-35
Western	Hard	50.1	59	15	45.1	59	16	47	-10
	Moderate	22.7	27	7	21.1	27	8	46	-7
	Soft	11.5	14	3	10.7	14	4	39	-7
	Alluvium	0.0	0	0	0.0	0	0	0	0
Subbasin Total		84.4	100	25	76.9	100	28	35	-9
Coastal	Hard	12.5	25	4	11.1	25	4	26	-12
	Moderate	27.9	56	8	24.8	57	9	32	-11
	Soft	9.4	19	3	8.0	18	3	37	-14
	Alluvium	0.0	0	0	0.0	0	0	0	0
Subbasin Total		49.8	100	15	43.9	100	16	28	-12
Study Area	Hard	158.7		48	127.4		47	47	-20
	Moderate	112.6		34	96.2		35	40	-15
	Soft	60.5		18	50.0		18	34	-17
	Bedrock Total	331.8		100	273.6		100	42	-18
	Alluvium	0.0		0	0.0		0		
Study Area Totals		**331.8**			**273.6**				

[1] Values are based on percentages of total inner gorge length and reflect the portions of inner gorges mapped outside of the blue-line streams.
[2] Values reflect the percentage of all blue-line stream segments within the specific subbasin and terrain.
[3] Values for the Estuary are "0" because the inner gorges mapped in hard and soft terrains are associated with the alluvial reach of the Mattole River.

Table 10. Blue-Line Stream Statistics.

Subbasin	Terrain	Subbasin/Terrain			Bedrock/Alluvium Contrast		
		Stream Length (miles)	% of total Stream Length [1]	Stream Density (miles/square mile)	Stream Length: Subbasin Total (miles)	Subbasin Total of % of Stream Length [1]	Subbasin Average of Stream Density (miles/square mile)
Estuary	Hard	0.7	0.1	2.0	Bedrock		
	Moderate	1.3	0.2	2.0	2.6	0.3	1.8
	Soft	0.6	0.1	1.2	Alluvium		
	Alluvium	4.3	1	7.7	4.3	1	7.7
Subbasin Total		7.0	1				
Northern	Hard	40.4	5	2.1	Bedrock		
	Moderate	52.2	6	1.8	165.4	19.5	1.8
	Soft	72.9	9	1.7	Alluvium		
	Alluvium	47.6	6	5.9	47.6	5.6	5.9
Subbasin Total		213.0	25				
Eastern	Hard	59.1	7	2.0	Bedrock		
	Moderate	67.2	8	2.0	150.6	18	2.0
	Soft	24.4	3	1.8	Alluvium		
	Alluvium	34.9	4	12.5	34.9	4	12.5
Subbasin Total		185.5	22				
Southern	Hard	30.3	4	1.3	Bedrock		
	Moderate	0.2	0.02	0.9	30.5	4	1.3
	Soft	0.0	0	0.0	Alluvium		
	Alluvium	38.8	5	10.9	38.8	5	10.9
Subbasin Total		69.3	8				
Western	Hard	96.1	11	2.1	Bedrock		
	Moderate	45.7	5	2.1	168.9	20	2.0
	Soft	27.2	3	1.6	Alluvium		
	Alluvium	49.0	6	7.9	49.0	6	7.9
Subbasin Total		217.9	26				
Coastal	Hard	42.2	5	2.1	Bedrock		
	Moderate	76.4	9	1.9	140.5	17	2.0
	Soft	21.9	3	2.0	Alluvium		
	Alluvium	14.2	2	3.0	14.2	2	3.0
Subbasin Total		154.7	18				
Study Area	Hard	268.7	32	2.0	Stream Length in Terrains as a % of all Bedrock Streams	41	
	Moderate	242.9	29	1.9		37	
	Soft	146.9	17	1.7		22	
	Bedrock Streams	658.6	78	1.9	658.6	78	1.9
	Alluvium	188.8	22	7.3	188.8	22	7.3
	All Streams	**847.4**	**100**	**2.3**	**847.4**	**100**	**2.3**

[1] Total length of all blue-line stream segments within the study area.

Table 11. Source, Transport, and Response Stream Reaches.

Subbasin	Terrain	Response Reach (<4% Gradient)			Transport Reach (4% - 20% Gradient)			Source Reach (>20% Gradient)		
		Length (miles)	% of Total Blue-Line Stream Length [1]	% of Total Response Reach in Study Area	Length (miles)	% of Total Blue-Line Stream Length [1]	% of Total Transport Reach in Study Area	Length (miles)	% of Total Blue-Line Stream Length [1]	% of Total Source Reach in Study Area
Estuary	**Hard**	0.1	0.01	0.04	0.6	0	0.20	0.0	0	0
	Moderate	0.1	0.01	0.03	0.1	0	0.02	1.2	0.1	0.4
	Soft	0.0	0.004	0.01	0.5	0	0.2	0.0	0	0
	Alluvium	4.2	1	1	0.0	0	0	0.0	0.004	0.01
Northern	**Hard**	9.4	1	3	15.5	2	5	15.5	2	5
	Moderate	8.9	1	3	22.2	3	7	21.0	2	7
	Soft	16.4	2	5	25.6	3	8	30.8	4	10
	Alluvium	39.8	5	13	7.1	1	2	0.7	0.1	0.2
Eastern	**Hard**	16.9	2	5	30.2	4	10	12.0	1	4
	Moderate	21.0	2	7	31.6	4	10	14.6	2	5
	Soft	5.2	1	2	10.3	1	3	9.0	1	3
	Alluvium	28.7	3	9	5.9	1	2	0.3	0.03	0.1
Southern	**Hard**	8.1	1	3	14.7	2	5	7.4	1	2
	Moderate	0.0	0.01	0.02	0.1	0	0.04	0.0	0	0
	Soft	0.0	0	0	0.0	0	0	0.0	0	0
	Alluvium	33.2	4	11	5.6	1	2	0.0	0	0
Western	**Hard**	24.2	3	8	41.1	5	13	30.8	4	10
	Moderate	14.7	2	5	19.4	2	6	11.6	1	4
	Soft	7.9	1	3	13.2	2	4	6.1	1	2
	Alluvium	43.8	5	14	4.7	1	1	0.5	0.1	0.2
Coastal	**Hard**	4.0	0.5	1	14.4	2	5	23.8	3	8
	Moderate	13.1	2	4	28.8	3	9	34.5	4	11
	Soft	5.5	1	2	12.1	1	4	4.3	1	1
	Alluvium	9.0	1	3	4.1	0	1	1.1	0.1	0.4
Study Area	Hard	62.7	7	20	116.6	14	38	89.5	11	40
	Moderate	57.8	7	18	102.2	12	33	83.0	10	37
	Soft	35.0	4	11	61.7	7	20	50.2	6	22
	Bedrock Total	155.5	18	49	280.5	33	91	222.7	26	99
	Alluvium	158.7	19	51	27.4	3	9	2.7	0.3	1
Study Area Totals		**314.2**		**100**	**307.8**		**100**	**225.4**		**100**
Reach as a % of Total Stream Length in the entire Study Area		**37**			**36**			**27**		

[1] Total length of all blue-line stream segments within the study area.

Table 12. Negative Mapped Channel Characteristics (NMCCs) [1].

Subbasin	Terrain	1984		2000		Change in NMCCs	
		NMCC Length [3] (miles)	% of Blue-Line Stream Segments affected by NMCC's [2]	NMCC Length [3] (miles)	% of all Blue-Line Stream Segments affected by NMCC's [2]	NMCC Length, 2000-1984 [4,5] (%)	Proportion of NMCC affected Stream Length [4,5] (%)
Estuary	Hard	0	0	0	0	0	0
	Moderate	0	0	0	0	0	0
	Soft	0	0	0	0	0	0
	Bedrock Total	0	0	0	0	0	0
	Alluvium	1.5	36	1.3	29	-18	-6
Subbasin Total		1.5	22	1.3	18	-18	-4
Northern	Hard	17.4	43	15.3	38	-12	-5
	Moderate	23.9	46	20.6	40	-14	-6
	Soft	19.3	27	20.3	28	5	1
	Bedrock Total	60.6	37	56.2	34	-7	-3
	Alluvium	22.8	48	21.3	45	-7	-3
Subbasin Total		83.4	39	77.4	36	-7	-3
Eastern	Hard	32.2	55	9.8	17	-70	-38
	Moderate	33.1	49	7.6	11	-77	-38
	Soft	5.0	20	1.6	6	-68	-14
	Bedrock Total	70.2	47	19.0	13	-73	-34
	Alluvium	7.1	20	7.6	22	8	2
Subbasin Total		77.3	42	26.6	14	-66	-27
Southern	Hard	13.7	45	1.5	5	-89	-40
	Moderate	0	0	0	0	0	0
	Soft	0	0	0	0	0	0
	Bedrock Total	13.7	45	1.5	5	-89	-40
	Alluvium	0.4	1.1	0.1	0.3	-73	-0.8
Subbasin Total		14.1	20	1.7	2	-88	-18
Western	Hard	33.1	34	12.3	13	-63	-22
	Moderate	22.4	49	10.2	22	-54	-27
	Soft	6.8	25	3.3	12	-52	-13
	Bedrock Total	62.2	37	25.8	15	-59	-22
	Alluvium	9.1	19	9.9	20	9	2
Subbasin Total		71.3	33	35.7	16	-50	-16
Coastal	Hard	7.9	19	2.5	6	-68	-13
	Moderate	16.7	22	15.3	20	-8	-2
	Soft	10.0	46	6.5	30	-35	-16
	Bedrock Total	34.6	25	24.3	17	-30	-7
	Alluvium	5.4	38	5.1	36	-6	-2
Subbasin Total		40.0	26	29.4	19	-26	-7
Study Area	Hard	104.2	39	41.5	15	-60	-23
	Moderate	96.1	40	53.8	22	-44	-17
	Soft	41.1	28	31.6	22	-23	-6
	Bedrock Total	241.4	37	126.8	19	-47	-17
	Alluvium	46.3	25	45.2	24	-2	-1
	Totals	**287.7**	**34**	**172.1**	**20**	**-40**	**-14**
% of all NMCC's found within Terrains							
Study Area	Hard		36		24		-12
	Moderate		33		31		-2
	Soft		14		18		4
	Bedrock Total		84		74		-10
	Alluvium		16		26		10

[1] Mapped channel characteristics used in this analysis include only those that connotate negative effects from excess sediment (See Table 3 for list.)

[2] Values reflect the percentage of blue-line streams segments within the specific subbasin and terrain that have been affected by NMCCs.

[3] Cumulative length of all stream segments identified as having been affected by NMCCs.

[4] Values in the "Change in NMCCs" column result from redistribution of relative percentages of NMCCs between bedrock and alluvium reaches caused by the reduction in the total length of NMCCs observed in bedrock reaches.

[5] Negative values indicate a reduction of NMCCs between 1984 and 2000. Positive values indicate an increase in NMCCs between 1984 and 2000.

Table 13. Blue-Line Stream Segments Crossing Bedrock and LPM 4 and 5 [1].

Subbasin	Terrain	Blue-Line Stream Segments Crossing LPM 4 and 5 [2] (miles)	% Total for Study Area [3]	All Blue-Line Streams in Bedrock Terrains (miles)	% of Total for Terrain/Subbasin [3]
Estuary	**Hard**	0.7	0	0.7	91
	Moderate	0.3	0	1.3	19
	Soft	0.5	0	0.6	84
Subbasin Bedrock Total		1.4	0	2.6	53
Northern	**Hard**	32.8	7	40.4	81
	Moderate	39.6	8	52.2	76
	Soft	64.0	13	72.9	88
Subbasin Bedrock Total		136.4	27	165.4	82
Eastern	**Hard**	37.7	8	59.1	64
	Moderate	38.7	8	67.2	58
	Soft	20.6	4	24.4	85
Subbasin Bedrock Total		97.0	20	150.6	64
Southern	**Hard**	17.9	4	30.3	59
	Moderate	0.0	0	0.2	22
	Soft	0.0	0	0.0	0
Subbasin Bedrock Total		18.0	4	30.5	59
Western	**Hard**	73.1	15	96.1	76
	Moderate	35.2	7	45.7	77
	Soft	21.6	4	27.2	79
Subbasin Bedrock Total		129.9	26	168.9	77
Coastal	**Hard**	37.1	7	42.2	88
	Moderate	59.8	12	76.4	78
	Soft	17.4	4	21.9	80
Subbasin Bedrock Total		114.4	23	140.5	81
Study Area	**Hard**	199.3	40	268.7	74
	Moderate	173.7	35	242.9	72
	Soft	124.1	25	146.9	84
	Totals/Averages	**497.1**	100	**658.6**	75

1 Landslide potential map categories 4 and 5 (high and very high landslide potential, respectively).
2 Cumulative total length of all blue-line stream segments within the identified terrain and subbasin that also lie within 150 feet of LPM categories 4 and 5.
3 Percentage of all blue-line stream segments in bedrock that are: 1) adjacent to or withiin LPM categories 4 and 5, and 2) affected by NMCCs.

Table 14. Negative Mapped Channel Characteristics (NMCCs) [1] near LPM 4 and 5 [2].

Subbasin	Terrain	1984			2000			Change in NMCC	
		NMCC Length [3] (miles)	Percent of Total NMCC Length in Bedrock, in or near LPM Categories 4 and 5 [2,3]	Percentage of all Blue-Line Stream Segments in Bedrock near LPM Categories 4 and 5 [2], that are affected by NMCC's	NMCC Length [3] (miles)	Percent of Total NMCC Length in Bedrock, in or near LPM Categories 4 and 5 [2,3]	Percentage of all Blue-Line Stream Segments in Bedrock near LPM Categories 4 and 5 [2], that are affected by NMCCs	NMCC Length [3,4], 2000-1984 (%)	Proportion of NMCC affected Stream Lengths [3,4] (%)
Estuary	**Hard**	0.0	0	0	0.0	0	0	0	0
	Moderate	0.0	0	0	0.0	0	0	0	0
	Soft	0.0	0	0	0.0	0	0	0	0
Subbasin Bedrock Total		0.0	0	0	0.0	0	0	0	0
Northern	**Hard**	17.7	100	54	15.6	99	48	-12	-6
	Moderate	24.7	100	62	21.1	100	53	-14	-9
	Soft	19.9	100	31	20.7	100	32	4	1
Subbasin Bedrock Total		62.3	100	46	57.5	100	42	-8	-4
Eastern	**Hard**	31.1	99	83	9.3	100	25	-70	-58
	Moderate	32.2	97	83	7.5	100	19	-77	-64
	Soft	4.8	99	24	1.4	100	7	-72	-17
Subbasin Bedrock Total		68.1	98	70	18.1	100	19	-73	-52
Southern	**Hard**	11.5	98	64	1.2	100	7	-90	-57
	Moderate	0.0	0	0	0.0	0	0	0	0
	Soft	0.0	0	0	0.0	0	0	0	0
Subbasin Bedrock Total		11.5	98	64	1.2	100	7	-90	-57
Western	**Hard**	31.5	100	43	11.4	100	16	-64	-27
	Moderate	19.0	100	54	9.1	100	26	-52	-28
	Soft	6.5	100	30	2.9	100	13	-55	-17
Subbasin Bedrock Total		56.9	100	44	23.5	100	18	-59	-26
Coastal	**Hard**	7.9	100	21	7.2	100	19	-9	-2
	Moderate	16.6	100	28	15.2	99	25	-8	-2
	Soft	8.5	100	49	5.9	100	34	-31	-15
Subbasin Bedrock Total		33.0	100	29	28.3	99	25	-14	-4
Study Area	**Hard**	99.7	100	50	44.7	100	22	-55	-28
	Moderate	92.5	99	53	52.9	100	30	-43	-23
	Soft	39.7	100	32	30.9	100	25	-22	-7
	Totals/Averages	**231.9**	**99**	**47**	**128.5**	**100**	**26**	**-45**	**-21**

1 Mapped channel characteristics used in this analysis include only those that connotate negative effects from excess sediment. (See Table 3 for list.)
2 Landslide potential map categories 4 and 5 (high and very high landslide potential, respectively).
3 Features lie within or are within 150 feet of LPM categorgies 4 and 5.
4 Negative values indicate a reduction of NMCCs between 1984 and 2000. Positive values indicate an increase in NMCCs between 1984 and 2000.

Table 15. Geologic Attributes Summary in the Mattole Basin.

	Estuary	Northern	Eastern	Southern	Western	Coastal
Predominant Geologic Unit(s)	Quaternary fluvial, beach, and dunes deposits	Franciscan Coastal Terrane; minor Yager terrane & Wildcat Group; Quaternary surficial deposits. Predominance of soft and moderate terrain.	Franciscan Central belt; Yager terrane; Coastal terrane. Approximately equal hard and moderate, with lesser soft terrain.	Franciscan Coastal terrane. Almost entirely hard terrain.	Franciscan Coastal terrane; King Range terrane. Approximately half is hard terrain, with remainder split evenly between moderate and soft terrains.	King Range terrane; Franciscan Coastal terrane
Predominant Rock/Soil Conditions	Unconsolidated, migrating sand and gravel deposits	Weak, broken argillite and mélange; thick, clayey soils	Intact sandstone and argillite cut by broad shear zones with weak rock and clayey soils	Relatively strong, intact sandstone and argillite; thin, sandy soils	Relatively intact sandstone and argillite in King Range; more broken in eastern and northern areas	Relatively intact sandstone and argillite in King Range; more broken in eastern and northern areas
Typical Mass Wasting	Sediment transport/ deposition	Abundant earthflows; rock slides; composite slides; gully and stream bank erosion	Debris and rock slides in strong rock areas; earthflows, composite slides and gullies around shear zones	Debris slides; scattered deep-seated rock slides	Debris slides, deep-seated rock slides and debris flows	Debris slides, deep-seated rock slides and debris flows
Relative Degree of "Mapped Channel Characteristics*"	N/A	Highest in basin	High in specific portions of subbasin	Lowest in basin	Highly variable throughout subbasin	N/A

* "Mapped channel characteristics" are stream features that may indicate excess sediment. See Table 3 for list of features.

Table 16. Fluvial-Geomorphic Features - Northern Subbasin.

	2000 Photos			1984 Photos		
Planning Watersheds[1]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]
Apple Tree	24,100	48,000	2-3	23,900	12,300	3-4
Camp Mattole	72,800	75,300	3-5	72,100	40,600	3-4
Cow Pasture Opening	30,600	50,500	1-2	24,900	11,600	2-3
Joel Flat	14,000	121,700	1-3	18,600	18,100	2-3
Long Ridge	37,000	96,600	4-5	48,900	51,000	4-5
McGinnis Creek	44,000	24,500	4-5	46,500	9,400	3-5
Oil Creek	73,900	123,000	4-5	68,600	48,100	4-5
Petrolia	34,500	74,100	3-5	39,000	25,400	4-5
Rainbow	63,000	87,200	4-5	69,000	27,500	4-5
Rattlesnake Creek	68,300	70,800	3-5	80,100	15,600	4-5
Northern Subbasin Totals	462,200	771,700		491,600	259,500	

[1] See Figure 2 for location.
[2] Features include negative and neutral characteristics including: wide channels, displaced riparian vegetation, point bars, distribution and lateral or mid-channel bars, channel bank erosion, shallow landslides adjacent to channels.
[3] Gullies include those that appear active, have little to no vegetation within the incised area, and are of sufficient size to be identified on aerial photos.
[4] Lateral bars include mappable lateral, mid-channel bars and reflect sediment supply and storage. Rankings range from 1-5. Higher values suggest excess sediment.

Table 17. Eroding Stream Bank Lengths - Northern Subbasin.

	2000 Photos			
Northern Subbasin Planning Watersheds[1]	Number of Sites[2]	Maximum Length (feet) of Eroding Bank[3]	Total Length (feet) of Eroding Bank[4]	Eroding Bank (%)[5]
Apple Tree	5	600	1,800	4
Camp Mattole	5	700	1,900	3
Cow Pasture Opening	2	500	700	<1
Joel Flat	1	400	400	1
Long Ridge	8	1,200	5,000	7
McGinnis Creek	7	1,600	3,600	5
Oil Creek	9	700	3,300	3
Petrolia	2	500	1,000	2
Rainbow	5	600	2,100	2
Rattlesnake Creek	12	2,900	8,200	9

[1] See Figure 2 for location.
[2] Number of sites mapped from air photos within PW.
[3] Maximum length of a continuous section of eroding stream bank within PW.
[4] Combined total length of all sections of eroding stream bank within PW.
[5] Approximate percentage of eroding stream bank relative to total stream length within PW.

Table 18. Fluvial-Geomorphic Features - Eastern Subbasin.

	2000 Photos			1984 Photos		
Planning Watersheds[1]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]
Blue Slide Creek	2,200	33,800	1	55,300	11,500	3-5
Dry Creek	46,800	17,400	2-4	65,500	2,100	3-5
Eubank Creek	13,400	22,400	1	56,600	27,500	1
Mattole Canyon	44,700	78,500	3-4	87,900	33,600	3-5
Sholes Creek	60,400	42,500	3-4	128,600	22,600	3-5
Westland Creek	26,200	35,100	3	59,500	8,100	3-5
Eastern Subbasin Totals	193,700	229,800		453,400	105,400	

[1] See Figure 2 for locations.
[2] Features include negative and neutral characteristics including: wide channels, displaced riparian vegetation, point bars, distribution and lateral or mid-channel bars, channel bank erosion, shallow landslides adjacent to channels.
[3] Gullies include those that appear active, have little to no vegetation within the incised area, and are of sufficient size to be identified on aerial photos.
[4] Lateral bars include mappable lateral, mid-channel bars and reflect sediment supply and storage. Rankings range from 1-5. Higher values suggest excess sediment.

Table 19. Eroding Stream Bank Lengths - Eastern Subbasin.

	2000 Photos			
Eastern Subbasin Planning Watersheds[1]	Number of Sites[2]	Maximum Length (feet) of Eroding Bank[3]	Total Length (feet) of Eroding Bank[4]	Eroding Bank (%)[5]
Blue Slide Creek	0	N.O.	N.O.	N.A.
Dry Creek	7	1,800	4,500	5
Eubank Creek	3	500	900	1
Mattole Canyon	1	300	300	<1
Sholes Creek	10	3,700	12,100	9
Westland Creek	3	800	1,600	2

1 See Figure 2 for locations.
2 Number of sites mapped from air photos within PW.
3 Maximum length of a continuous section of eroding stream bank within PW.
4 Combined total length of all sections of eroding stream bank within PW.
5 Approximate percentage of eroding stream bank relative to total stream length within PW.

N.O.– Not Observed.
N.A. – Not Applicable.

Table 20. Fluvial-Geomorphic Features - Southern Subbasin.

	2000 Photos			1984 Photos		
Planning Watersheds[1]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]
Bridge Creek	7,400	N.O.	1	58,900	N.O.	1
Thompson Creek	1,400	N.O.	1	15,800	N.O.	1
Southern Subbasin Totals	8,800			74,700		

[1] See Figure 2 for locations.
[2] Features include negative and neutral characteristics including: wide channels, displaced riparian vegetation, point bars, distribution and lateral or mid-channel bars, channel bank erosion, shallow landslides adjacent to channels.
[3] Gullies include those that appear active, have little to no vegetation within the incised area, and are of sufficient size to be identified on aerial photos.
[4] Lateral bars include mappable lateral, mid-channel bars and reflect sediment supply and storage. Rankings range from 1-5. Higher values suggest excess sediment.

N.O. – Not Observed.

Table 21. Eroding Stream Bank Lengths - Southern Subbasin.

	2000 Photos			
Southern Subbasin Planning Watersheds[1]	Number of Sites[2]	Maximum Length (feet) of Eroding Bank[3]	Total Length (feet) of Eroding Bank[4]	Eroding Bank (%)[5]
Bridge Creek	N.O.	N.O.	N.O.	N.A.
Thompson Creek	N.O.	N.O.	N.O.	N.A.

[1] See Figure 2 for locations.
[2] Number of sites mapped from air photos within PW.
[3] Maximum length of a continuous section of eroding stream bank within PW.
[4] Combined total length of all sections of eroding stream bank within PW.
[5] Approximate percentage of eroding stream bank relative to total stream length within PW.

N.O.- Not Observed.
N.A. – Not Applicable.

Table 22. Fluvial-Geomorphic Features - Western Subbasin.

	2000 Photos			1984 Photos		
Planning Watersheds[1]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]
Bear Creek, North Fork	24,700	28,000	2-3	57,300	8,000	3-4
Bear Creek, South Fork	8,400	8,500	1-2	24,000	4,100	2-3
Big Finely Creek	14,800	15,000	1-2	62,000	8,700	3-4
Honeydew Creek	48,600	38,200	3	74,000	17,200	3-4
Shenanigan Ridge	67,000	5,200	2-3	49,300	6,300	1-2
Squaw Creek	47,900	61,600	2	100,100	42,600	3-4
Woods Creek	32,600	24,200	2-3	54,000	4,800	3
Western Subbasin Totals	244,000	180,700		420,700	91,800	

[1] See Figure 2 for locations.
[2] Features include negative and neutral characteristics including: wide channels, displaced riparian vegetation, point bars, distribution and lateral or mid-channel bars, channel bank erosion, shallow landslides adjacent to channels.
[3] Gullies include those that appear active, have little to no vegetation within the incised area, and are of sufficient size to be identified on aerial photos.
[4] Lateral bars include mappable lateral, mid-channel bars and reflect sediment supply and storage. Rankings range from 1-5. Higher values suggest excess sediment.

Table 23. Eroding Stream Bank Lengths - Western Subbasin.

	2000 Photos			
Western Subbasin Planning Watersheds[1]	Number of Sites[2]	Maximum Length (feet) of Eroding Bank[3]	Total Length (feet) of Eroding Bank[4]	Eroding Bank (%)[5]
Bear Creek, No. Fork	6	700	2,700	2
Bear Creek, So. Fork	N.O.	N.O.	N.O.	N.O.
Big Finely Creek	3	800	1,500	2
Honeydew Creek	11	600	4,100	2
Shenanigan Ridge	2	300	600	<1
Squaw Creek	10	1,700	5,700	3
Woods Creek	4	1,400	3,500	8

[1] See Figure 2 for locations.
[2] Number of sites mapped from air photos within PW.
[3] Maximum length of a continuous section of eroding stream bank within PW.
[4] Combined total length of all sections of eroding stream bank within PW.
[5] Approximate percentage of eroding stream bank relative to total stream length within PW.

N.O.- Not Observed.

Table 24. Fluvial-Geomorphic Features - Coastal Basins.

	2000 Photos			1984 Photos		
Planning Watersheds[1]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]	Length of Mapped Channel Characteristics[2] (feet)	Total Gully Length[3] (feet)	Lateral Bar Development[4]
Big Creek	20,100	1,600	1	22,500	N.O.	1
Cooskie Creek	42,700	127,400	1	71,400	64,100	1
Gitchell Creek	20,200	3,300	1	33,300	4,100	1
McNutt Gulch	37,100	115,800	1	31,200	52,200	1
Punta Gorda	25,400	53,900	1	21,900	13,700	1
Shipman Creek	28,000	N.O.	1	21,500	N.O.	1
Whale Gulch	6,400	500	1	9,600	900	1
Coastal Subbasin Total	179,900	302,500		211,400	135,000	

[1] See Figure 2 for locations.
[2] Features include negative and neutral characteristics including: wide channels, displaced riparian vegetation, point bars, distribution and lateral or mid-channel bars, channel bank erosion, shallow landslides adjacent to channels.
[3] Gullies include those that appear active, have little to no vegetation within the incised area, and are of sufficient size to be identified on aerial photos.
[4] Lateral bars include mappable lateral, mid-channel bars and reflect sediment supply and storage. Rankings range from 1-5. Higher values suggest excess sediment.

N.O. – Not Observed.

Table 25. Eroding Stream Bank Lengths - Coastal Basins.

	2000 Photos			
Coastal Subbasin Planning Watersheds	Number of Sites[1]	Maximum Length (feet) of Eroding Bank[2]	Total Length (feet) of Eroding Bank[3]	Approx. % Eroding Bank to Total Stream Length[4]
Big Creek	4	2,200	4,700	6
Cooskie Creek	5	1,700	3,800	2
Gitchell Creek	5	1,200	3,500	3
McNutt Gulch	11	1,000	4,300	3
Punta Gorda	2	400	800	1
Shipman Creek	7	1,400	3,900	3
Whale Gulch	1	500	500	1

[1] Number of sites mapped from air photos within PW.
[2] Maximum length in meters of a continuous section of eroding stream bank within PW.
[3] Combined total length in meters of all sections of eroding stream bank within PW.
[4] Approximate percentage of eroding stream bank relative to total stream length within PW.

APPENDIX 1

Glossary of Terms and Acyronyms

Glossary of Terms

Activity – The recency of movement of a landslide, assessed using the freshness of features as outlined in Keaton and DeGraff (1996).

Historically-active – movement within the last 100 to 150 years, as interpreted from aerial photographs. Landslide features have crisp and sharp scarps and flanks, and vegetation is typically absent on scarps.

Dormant-young – landslide features are still clearly recognizable, with drainages just becoming established along the lateral margins of the slide mass.

Dormant-mature – landslide features are still recognizable, but have been "smoothed over" significantly, with drainages being incised into the body of the slide.

Dormant-old – landslides have been extensively modified by stream and/or weathering activities.

Alluvium – A general term for detrital deposits made by streams on river beds, flood plains, and alluvial fans. The term applies to stream deposits of recent time.

Blue-line stream – Streams that are depicted as blue lines on USGS 7.5-minute quadrangle maps. In general, streams greater than 2,500 feet in length are included, and streams are extended upslope to the point where the channel is no longer evident from the air photos utilized.

Colluvium – A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff and brought there chiefly by gravity.

Debris flow/debris torrent – A landslide characterized by the extremely rapid movement of water-laden debris. See Appendix 2 for further description.

Debris slide – A landslide characterized by weathered and fractured rock, collluvium, and soil that moves downslope along a relatively shallow translational failure plane. See Appendix 2 for further description.

Debris slide slope – A geomorphic feature in which the slope has been sculpted by numerous debris-slide events. See Appendix 2 for further description.

Disrupted ground - Irregular ground surface caused by complex landsliding processes resulting in features that are indistinguishable or too small to delineate individually at 1:24,000 scale. May also include areas affected by downslope creep, expansive soils, and/or gully erosion. See Appendix 2 for further description.

Earthflow – A landslide characterized by slow to rapid flowage of saturated rock, soil and debris in a semi-viscous, highly-plastic state. See Appendix 2 for further description.

Gully – Distinct, narrow channel formed by erosion of soil or soft rock material by running water. See Appendix 2 for further description.

Inner gorge – A geomorphic feature formed by coalescing scars originating from landsliding and erosional processes caused by active stream erosion. See Appendix 2 for further description.

Mainstem – The principal, largest, or dominating stream or channel of any given area or drainage system.

Mapped channel characteristics (MCCs) – Fluvial features recorded during this study. Includes general channel attributes, as well as features indicative of channel instability or sediment storage. MCCs are listed in Table 3, and Appendix 3 is a photographic dictionary of these features.

Mélange – A mappable body of rock that includes fragments and blocks of all sizes, both exotic and native, embedded in a fragmented and generally sheared, clay-rich matrix.

Negative mapped channel characteristics (NMCCs) – Those fluvial features that are considered to suggest excess sediment production, transport and/or deposition. NMCCs are shown in bold on Table 3.

Planning watersheds (PWs) – Subwatersheds within the study area defined by the Calwater 2.2a program. The planning watersheds within the Mattole study area are shown in Figure 2.

Rockslide – A landslide characterized by a relatively cohesive slide mass and a failure plane that is relatively deep-seated. Rockslides were referred to in previous CGS publications as “translational/rotational slides.”

Terrain – A tract or region of the earth’s surface considered as a physical feature. *Geomorphic terrains*, as used in this report, are regions of similar topographic form as first described in Ellen and others (1982). The geomorphic terrains are correlated to landslide density and landslide type.

Terrane – A term applied to a rock or group of rocks and to the area in which they crop out. The term is used in a general sense and does not imply a specific rock unit.

Watershed – Total land area draining to any point in a stream. Also called catchment area or basin.

Watershed Assessment – An interdisciplinary process of information collection and analysis that characterizes current watershed conditions at a coarse scale.

List of Acronyms

CGS – California Geological Survey
cfs – cubic feet per second
DEM – digital elevation model
DMG – California Division of Mines and Geology (now called California Geological Survey)
DOD – United States Department of Defense
DOQ – digital orthophoto quadrangle
GIS – geographic information system
LPM – landslide potential map
MCC – mapped channel characteristics
NCWAP – North Coast Watershed Assessment Program
NMCC – negative mapped channel characteristics
PW – planning watershed
USDA – United States Department of Agriculture
USGS – United States Geological Survey

APPENDIX 2

Landslide Type and Associated Geomorphic Features

The terminology used in this document and the accompanying map (Plate 1) to describe landslide types and geomorphic features related to landsliding were updated from DMG Note 50. The terminology and language are derived from the previous Watersheds Mapping program conducted by DMG in the early 1980's. Several quadrangles within the Mattole watershed were mapped during that program. Our nomenclature is consistent with that presented in Cruden and Varnes (1996), and our mapping protocols and assessment of activity follows that proposed by Keaton and DeGraff (1996).

Rockslide

Referred to in previous CGS publications as translational/rotational, this slide type is characterized by a somewhat cohesive slide mass and a failure plane that is relatively deep-seated when compared to that of a debris slide of similar areal extent. The sense of the motion is linear in the case of a translational slide, and is arcuate or "rotational" in the case of the rotational slide. Complex versions involving rotational heads with translation or earthflow downslope are quite common.

Rockslides generally involve relatively cohesive bedrock. The bedrock is typically weaker near the surface due to weathering; however, sliding is not restricted to the zone of weathering. Failure commonly occurs along bedding planes, fractures, or other discontinuities in the bedrock. The concentric, downward movement of slide materials generally exposes a near vertical scarp in the head region and, occasionally, along the lateral margins of the slide. Slide materials are characterized by hummocky topography consisting of rolling, bumpy ground, frequent benches, and depressions. The toe of the slide may be steep where slide material has accumulated. Although the removal of root support is not likely to affect the overall stability of the slide mass, large clear-cuts (relative to slide size) could raise the groundwater table and induce instability. The removal of toe materials on smaller slides may reactivate the entire slide area.

Earthflow

An earthflow is a landslide resulting from slow to rapid flowage of saturated rock, soil and debris in a semi-viscous, highly-plastic state. After initial failure, an earthflow may move, or creep, seasonally in response to destabilizing forces.

Earthflows are typically composed of clay-rich materials that swell and lose much of their already-low shear strength when wet. When saturated, the fine-grained, clay-rich matrix may carry larger, more resistant boulders with it in slow, creeping movements. Slide materials erode easily, resulting in gullying and irregular drainage patterns. The irregular, hummocky ground characteristic of earthflows is generally free of conifers; grasslands and meadows predominate. Failures commonly occur on slopes that are gentle to moderate, although they may also occur on steeper slopes where vegetation has been removed. Undercutting of the toe of an earthflow is likely to reactivate downslope movement.

Debris Slide

A debris slide is characterized by weathered and fractured rock, colluvium, and soil that have moved downslope along a relatively shallow translational failure plane. Debris slides form steep, unvegetated scars in the head region and irregular, hummocky deposits (when present) in the toe region. Debris slide scars are likely to ravel and remain unvegetated for many years. Revegetated scars can be recognized by the even-faceted nature of the slope, steepness of the slope, and the lightbulb-shaped form left by many mid- and upper-slope failures.

Debris slides are most likely to occur on slopes greater than 65 percent where unconsolidated, non-cohesive, and rocky colluvium overlies a shallow soil/bedrock interface. The shallow translational slide surface is usually less than 15 feet deep. The probability of sliding is low where bedrock is exposed, except where weak bedding planes or fractures are oriented parallel to the slope. The presence of near surface bedrock creates a shallow, impervious slide plane that restricts the vertical movement of water and tends to concentrate subsurface water flow parallel to the slope. For this reason, sliding often occurs during high intensity storms. Springs may be present where water has concentrated along the slide plane. Because the removal of root support is likely to change the slope hydrology and shear strength of debris slide deposits, the vegetative cover where present is important to slope stability.

Debris Flow/Torrent Track

Debris flow and debris torrent tracks are characterized by long stretches of bare, generally unstable stream channel banks that have been scoured and eroded by the extremely rapid movement of water-laden debris. They commonly are caused by debris sliding or the failure of fill materials along stream crossings in the upper part of a drainage during high intensity storms.

Debris flow/torrent tracks are formed by the failure of water-charged soil, rock, colluvium, and organic material down steep stream channels. They are often triggered by debris slide movement on adjacent hill slopes and by the mobilization of debris accumulated in the stream channels themselves. Debris flows and torrents commonly entrain large quantities of inorganic and organic material from the streambed and banks. Occasionally, the channel may be scoured to bedrock. When momentum is lost, scoured debris may be deposited as a tangled mass of large organic debris in a matrix of sediment and finer organic material. Such debris may be reactivated or washed away during subsequent events. The erosion of steep debris slide-prone stream banks below the initial failure may cause further failure downstream. The potential for failure is largely dependent upon the quantity and stability of soil and organic debris in a stream channel and the stability of adjacent hill slopes. The location of roads and landings upslope also affects landslide potential.

Gully

Gullies are erosional channels produced by running water in earth or unconsolidated material. The channels usually carry water only during and immediately after heavy rains. They generally have steep sides and near-vertical headcuts, which are generally unvegetated. Gullies typically increase in size by surface flow concentrated near the gully's head, and by subsurface flow undercutting the head scarp or the gully walls.

Readily erodible soil is susceptible to gully formation and continued enlargement. In the forest environment, gullies form because of the concentration of surface runoff along roads. Changes in vegetation cover affect gully formation and enlargement primarily in two ways. Vegetation changes that result in concentrating surface water runoff enhance gullying by surface erosion of sediment particles in the headwall area. Changes in vegetation cover that increase infiltration can also result in increased ground-water underflow and piping. Permeability discontinuities in the shallow subsurface can concentrate ground-water underflow and result in piping and subsurface erosion.

Debris Slide Slope

Debris slide slopes and amphitheaters are geomorphic features in which slopes have been sculpted by numerous debris slide events. The slopes are characterized by an aggregate of debris slide scars left by the movement of rock, colluvium, and soil along relatively shallow failure planes.

Debris slide slopes are characterized by generally well-vegetated soils and colluvium above a shallow soil/bedrock interface. The slopes may contain areas of active debris sliding or bedrock exposed by former debris sliding. Although the slopes often are smooth, steep (often greater than 65 percent), and unbroken by benches, they are characteristically dissected by closely-spaced incipient drainage depressions. In many places, perennial channels within the amphitheaters and slopes are deeply incised with steep walls of rock or colluvial debris. The presence of linear or teardrop-shaped, even-aged stands of trees, beginning at small scarps or spoon-shaped depressions, is indicative of former debris slide activity.

The presence of bedrock or impervious material at shallow depths may concentrate subsurface water flow, and springs may be present where permeable zones above the restrictive layer are saturated. Because soil and colluvial materials are thin, the vegetative cover, where present, and the associated root strength is important to slope stability. Root removal can also change slope hydrology including a rise in ground-water level, which can further destabilize the slope. Slopes near the angle of repose may be relatively stable except where weak bedding planes and bedrock joints and fractures are sub-parallel to the slope angle. The placement of fill materials on steep, unconsolidated upslope deposits also increases landslide potential. Therefore, the intensity of road networks and the location of roads and drainage structures are particularly important to slope stability in debris slide amphitheaters and on debris slide slopes. Areas adjacent to recent slides have increased potential for sliding.

Inner Gorge

An inner gorge is a geomorphic feature formed by coalescing scars originating from landsliding and erosional processes caused by active stream erosion. The feature is identified as that area of stream bank situated immediately adjacent to the stream channel, having a side slope of generally over 65 percent, and being situated below the first break in slope above the stream channel.

Inner gorges are formed dominantly by debris slide processes that have been activated by the downcutting of stream channel bottoms. They commonly form along toes of large upslope landslide deposits undercut by stream erosion. Where bedrock is exposed, the inner gorge may be relatively stable. Where shallow, permeable, non-cohesive soils and colluvium overlie impervious bedrock and/or slide plane materials, subsurface water flow may be concentrated along the steep stream bank slopes and springs may be present. Slope stability is affected by high intensity storms by the undercutting of stream banks because of the rising the stream level. Road cuts, as well as stream-bank erosion, are likely to activate or reactivate downslope movement. The addition of fill and/or concentration of water from roads and landings above the inner gorge could also increase landslide potential. Because unvegetated scars are likely to ravel, root support and vegetation are important to the overall slope stability.

APPENDIX 3

Photographic Dictionary of Mapped Channel Characteristics

Photographic Dictionary of Mapped Channel Characteristics

This stream characteristics aerial photo mapping dictionary documents the general appearance of stream and stream channel influencing features that are mapped by the California Geological Survey's NCWAP staff for the fluvial geomorphic component. These images are only an example of each characteristic, but are generally representative. Most of the images in this document were take from the USGS digital orthophoto quadrangles (DOQs). Some copyrighted images are used with permission and taken from aerial photos provided by WAC Corporation (www.waccorp.com).

Channel characteristics are generally only visible when the channel canopy cover is sufficiently open to allow observation and observations are dependent on imagery scale and quality. These limitations are fundamental to all remote sensing methods. Nevertheless, the use of aerial photo mapping of channel geomorphic characteristics taken at different times allows for documentation and detection of channel change. These mapped channel characteristics can be used in assessing relative channel changes, aid in delineation of areas for field studies and document channel associations with upland characteristics and processes. Fluvial geomorphic features mapped by aerial photo interpretation should be considered reconnaissance data.

For the purpose of the Ecological Management Decision System (EMDS) watershed modeling exercise, some channel characteristics were considered indicators of excess sediment in storage or sediment sources that are less than optimum for fishery habitat. These characteristics are used in the development of the EMDS model's relative ranking of watershed channel geomorphic conditions. The EMDS modeling used only the primary data field characteristic (sed_type1) for relative ranking. The attributes shown in Table 1 in bold italics are those that may be indicators of excess sediment in storage or sediment sources that could be considered detrimental to optimum habitats for anadromous salmonids. While most of these features are always associated with increased sediment or impaired conditions, others, such as lateral bar, may or may not represent impairment. The actual fisheries habitat value should be determined through field surveys.

Observations and information from aerial photos are used to attribute mapped channel features in the GIS database. These attributes are considered only spatially associated geomorphic observations and should not be interpreted as evidence of cause-and-effect. Other geologic, geomorphic, biologic and hydrologic information, which cannot be observed or interpreted from aerial photos, may be relevant or causal to the mapped stream channel characteristic and its significance to stream habitat. Determination of cause-and-effect of a characteristic mapped by aerial photo interpretation requires that site specific investigations be done to confirm, or modify, remotely sensed interpretations.

Descriptions provided in this document are photo interpretation characteristics. Readers who want more details on the causes of these channel geomorphic characteristics, the interrelationships between various characteristics and their significance to channel form and function might want to refer in part to some of the publications listed below.

Database Dictionary for GIS Mapped Fluvial Geomorphic Attributes

sed_type1 - primary channel characteristic
sed_type2,3,4 - secondary channel characteristic (if noted)

wc - wide channel	***ag – aggrading reach***
br – braided channel	***dg – degrading reach***
rf – riffle	***in – incised reach***
po – pool	ox – oxbow meander
fl – falls	ab – abandoned channel
uf – uniform flow	am – abandoned meander
tf – turbulent flow	***cc – cutoff chute***
bw – backwater reach	***tf – tributary fan***
pb - point bar	lj - log jam
lb - lateral bar	***ig - inner gorge***
mb – mid-channel bar	***el - eroding left bank (facing downstream)***
jb - bar at junction of channels	***er - eroding right bank (facing downstream)***
tb - transverse bar	***la - active landslide deposit***
vb - vegetated bar	***lo - older landslide deposit***
vp - partially vegetated bar	***dr – displaced riparian vegetation***
bc – blocked channel	ms – man-made structure

Attributes shown in bold italics may be indicators of excess sediment in storage or sediment sources that could be considered detrimental to optimum habitats for anadromous salmonids

Selected References on Fluvial Geomorphology and Hydrology

Gordon, N.D., McMahon, T.A., Finlayson, B.L., 1992, Stream hydrology, an introduction for ecologists: John Wiley and Sons, New York, New York, 526 p.

Knighton, D., 1998, Fluvial Forms and Processes, A New Perspective: Arnold Publishers, London, co-published by John Wiley and Sons, New York, New York, 383 p.

Leopold, L.B., Wolman, M.G., Miller, J.P., 1964, Fluvial processes in geomorphology: 1992 reprint by Dover Publications, New York, 522 p.

Rosgen, D., 1996, Applied river morphology: Wildland Hydrology, Pagosa Springs, Colorado.

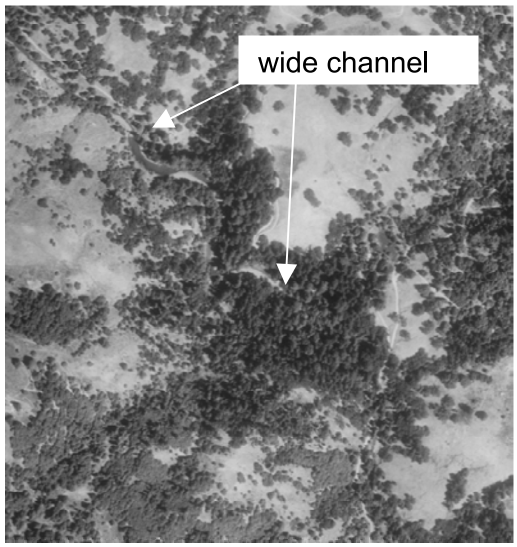
Ritter, D.F., Kochel, R.C., and Miller, J.R., 1995, Process geomorphology, Third Edition: Wm.C Brown Publisher, Boston, Massachusetts, 546 p.

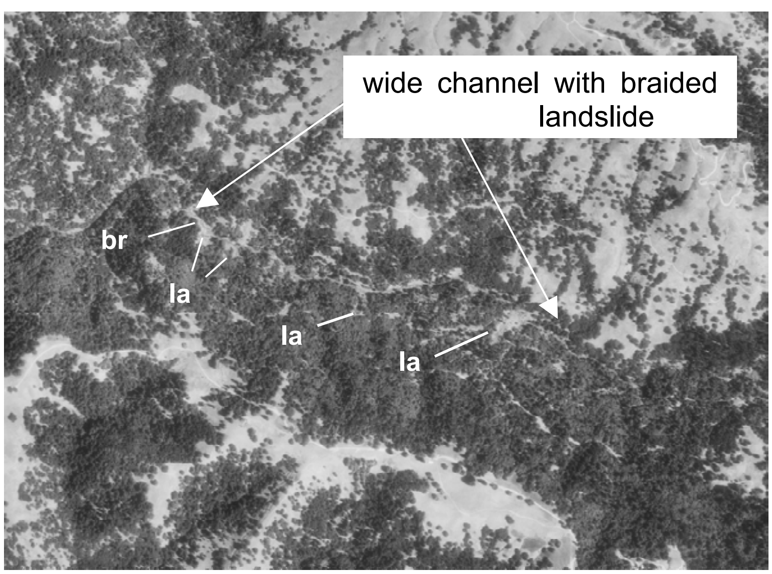
Thorne, C.R., Stream reconnaissance handbook, geomorphological investigations and analysis of river channels: John Wiley and Sons, New York, New York, 133 p.

Thorne, C.R., Hey, R.D., Newson, M.D., 1997, Applied fluvial geomorphology for river engineering and management: John Wiley and Sons, New York, New York, 376 p.

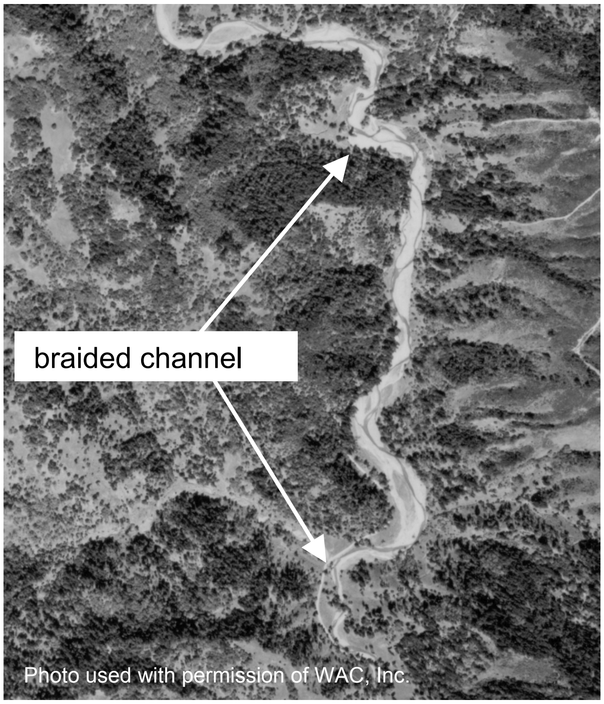
Wohl, E., 2000, Mountain rivers: Water Resources Monograph 14, American Geophysical Union, Washington D.C., 320 p.

Wide channel (wc)– characteristic is mapped when width of channel sediment is anomalous to the surrounding channels of similar order. This mapped characteristic varies across the watershed based on local geologic and geomorphic conditions and vegetation density and types. Typically, additional attributes are included to describe channel characteristics associated with the increase in channel width. The *wc* attribute is also used whenever the resolution of the image prevented clear identification of ground features, but the anomalous lack or disturbance of channel riparian vegetation suggests excess sediment deposition. The *wc* condition is often found at or near the same sections of channel in photos of different years and is often mapped adjacent to a landslide.





Braided channel (br) – characteristic is mapped when channel is a multi-threaded, interlaced streams within the active channel. A braided channel is commonly associated with an aggraded reach.

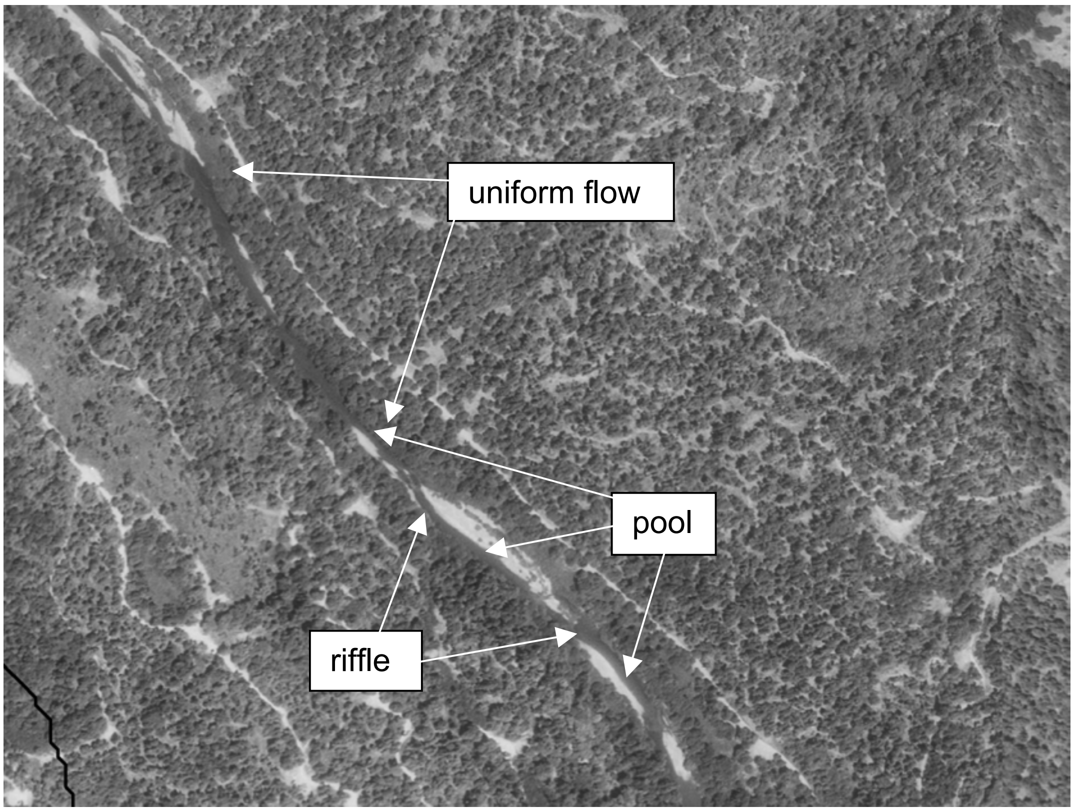


Falls (fl) – characteristic is generally not visible on reconnaissance aerial photos and therefore seldom mapped from photos at a scale of 1:12,000 or smaller. This characteristic is generally a point feature and would commonly be mapped in a site specific field study.

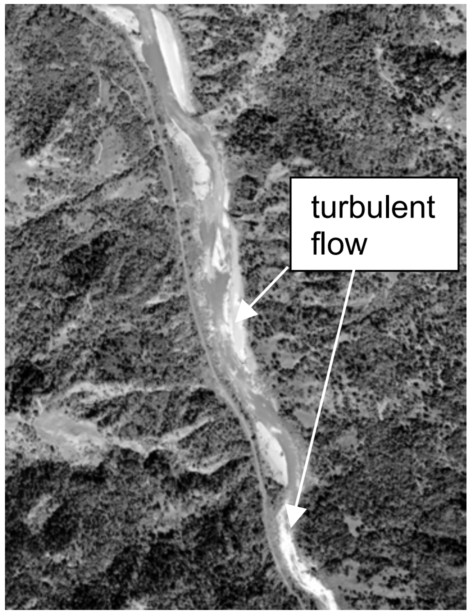
Riffle (rf) – characteristic is generally not mapped at the 1:24,000 reconnaissance scale because of small size and great number. This attribute is included in the database for completeness to facilitate mapping at a larger scale, and for mapping specific reaches. This feature is mapped between pools with no distinction made for runs or glides. This characteristic is best mapped as a point feature.

Pool (po) – characteristic is generally not mapped at the 1:24,000 reconnaissance scale because of small size and great number. This attribute is included in the database for completeness to facilitate mapping at a larger scale, and for mapping specific reaches. This feature is mapped at the outside of meanders or channel bends. This characteristic is best mapped as a point feature.

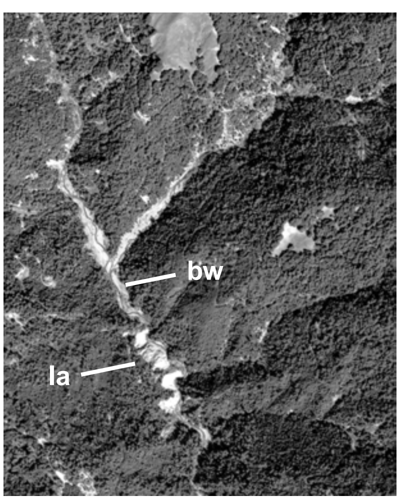
Uniform flow (uf) – characteristic is generally not mapped at the 1:24,000 reconnaissance scale since most channel flow appears calm at this scale. This characteristic is used for reach-specific studies and provided for completeness and as a contrast to turbulent flow characteristic that may be mapped at a reconnaissance scale, if extensive. This feature has some dependency on river stage as higher flows will submerge objects and hide channel complexity and turbulence.



Turbulent flow (tf) – characteristic is mapped whenever the channel water shows signs of excessive whitewater, suggesting that large obstacles occur within the active channel. This feature usually is a secondary attribute. This feature has some dependency on river stage as higher flows will submerge objects and hide channel complexity that may be the source of stream turbulence at lower discharges.

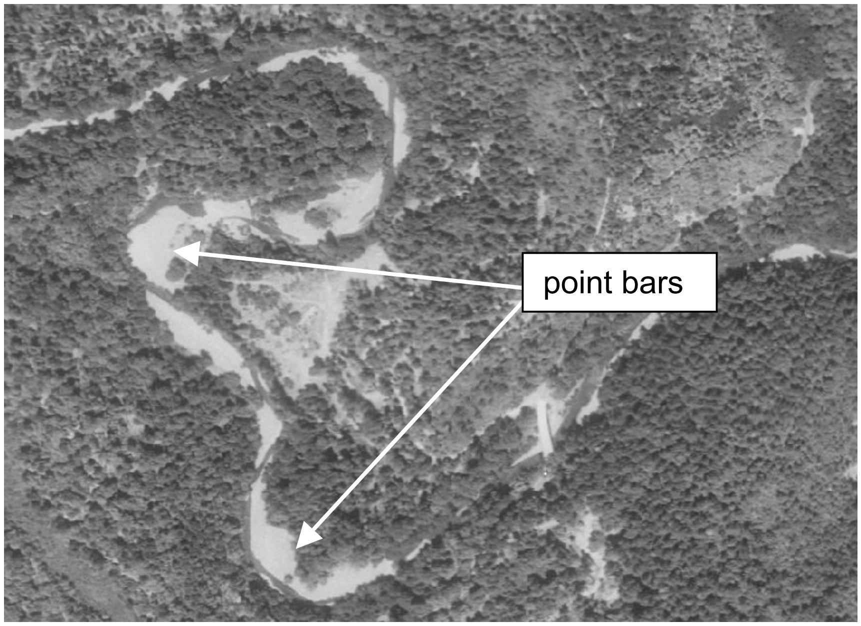


Backwater reach (bw) – characteristic is mapped when sediment deposits built up at the mouth of a tributary channel as it joins with a larger river or due to channel constriction or blockage, such as a delivering landslide. Deposition is generally caused by a slowing and blocking of storm flows as they try to merge with the main channel or flow through a constriction. Changes in channel gradient are often associated with areas of backwater. Since this characteristic is observable on an aerial photo it is much larger than backwater areas mapped in channel habitat surveys. Channel deposits in sections of backwater often cause low flows to go partially or completely into the subsurface.

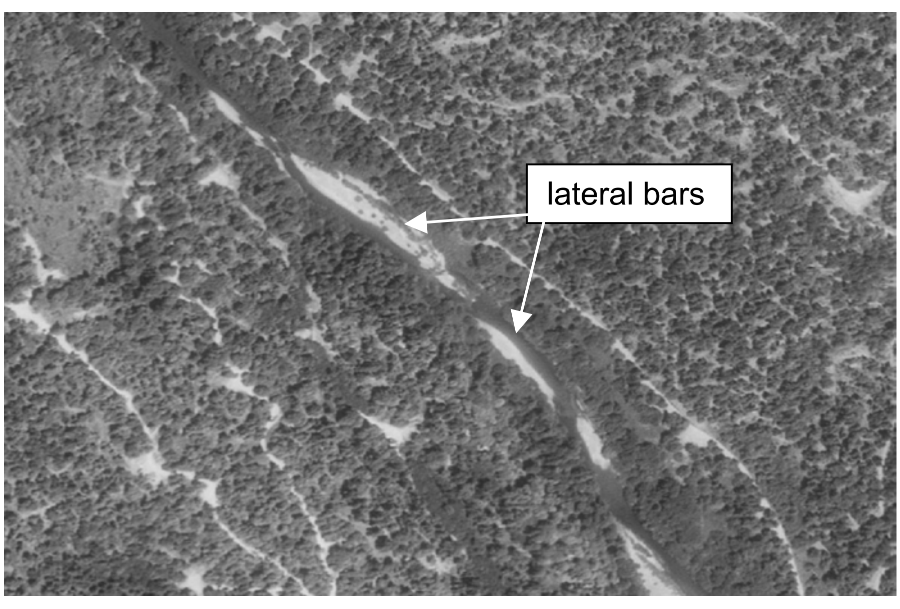


Flow backwaters (bw) as channel is constricted by toe of active landslide (la) causing sediments to deposit upstream of constriction.

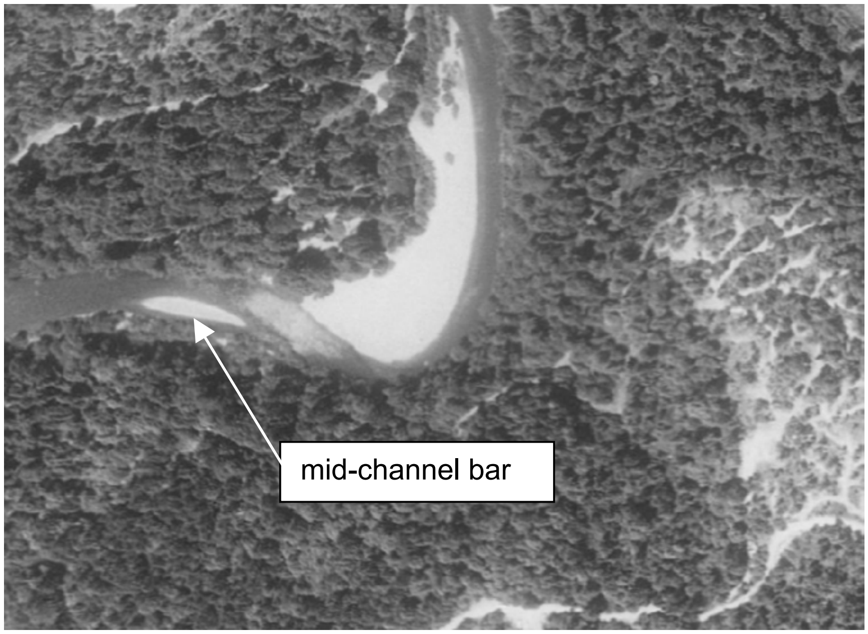
Point bar (pb)– characteristic is mapped at the inside bank of a channel meander. This feature is distinguished from the lateral bar by its greater plan curvature. Location of point bar sediment deposits is generally forced and controlled by the effects of channel curvature.



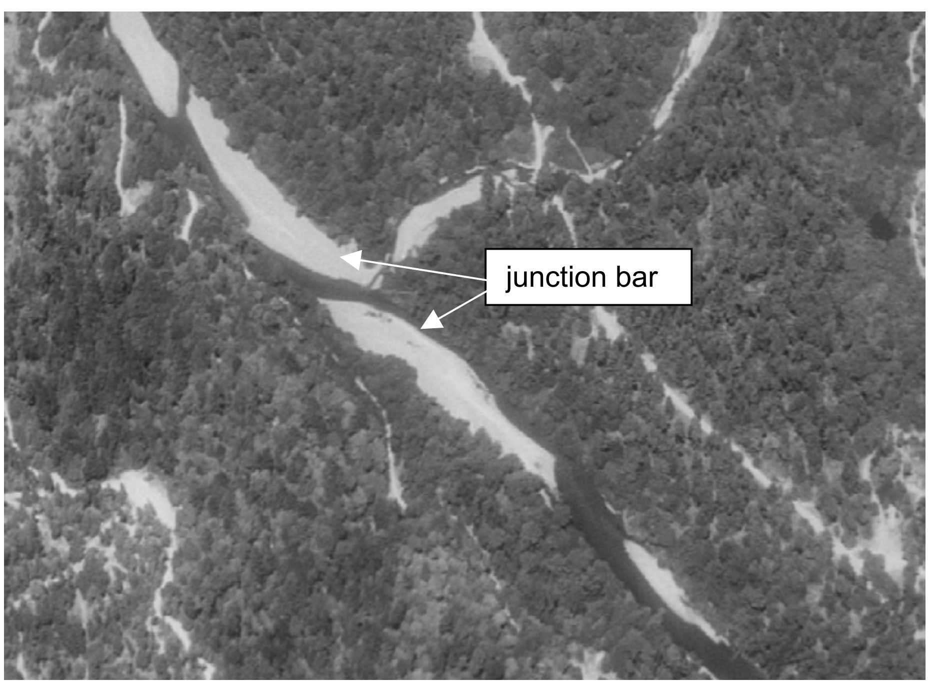
Lateral bar (lb) – characteristic mapped when sediment deposits are aligned sub-parallel with the channel boundary and not on sharp radius meanders. Groups of lateral bars may alternate back and forth from across the active channel forming a set of large radius meanders. Lateral bars are often found where banks are eroding or at the toe of a landslide that delivers sediment to the stream. Lateral bars are free to develop and migrate in response to changes in sediment load, channel flow and transport capacity.



Mid-channel bar (mb) – characteristic is mapped when elongated bars are found in the center of channel and water is flowing on both sides. This feature differs from transverse bars in its central channel position, general diamond or lobate shape, and lower number of chutes dissecting the bar.



Bar at junction of channels (jb) – characteristic is mapped when a bar(s) develops at the mouth of tributary stream. Most of the bar mass is within main channel, but some may extend up into the tributary. This characteristic is distinguished from a tributary fan because these bars are mostly within the active channel. Tributary deposits may also be associated with an area of backwater.

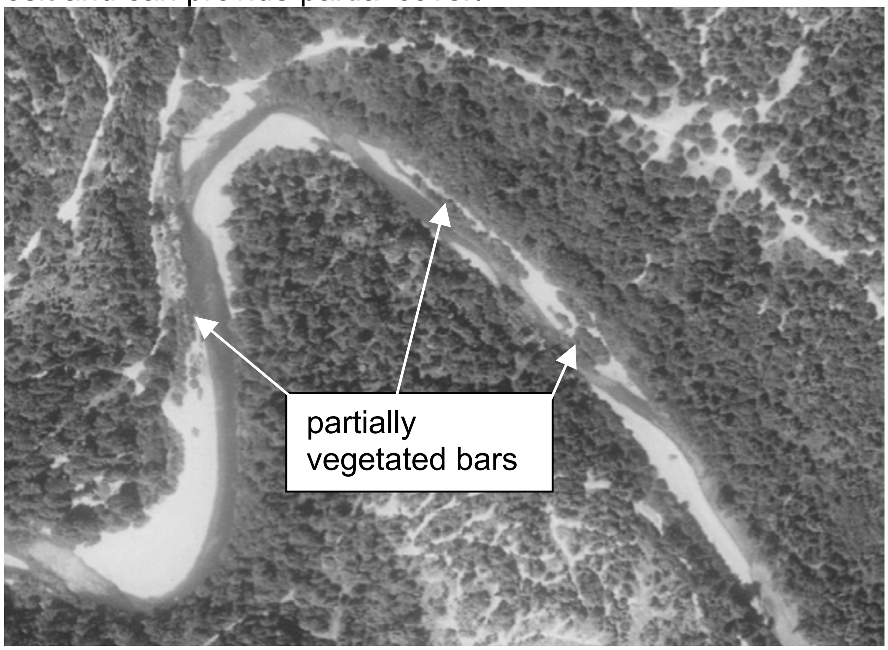


Transverse bar (tb) – characteristic is mapped when a series of bars develops across or at an angle diagonal to the active channel. This characteristic differs from a braided channel in the lesser number of bars developed along the length of channel and less extensive development of chutes to dissect the bars and form channel meanders. Differs from a mid-channel bar in that there are multiple chutes dissecting the bar deposits and the bars may be attached to the bank(s).

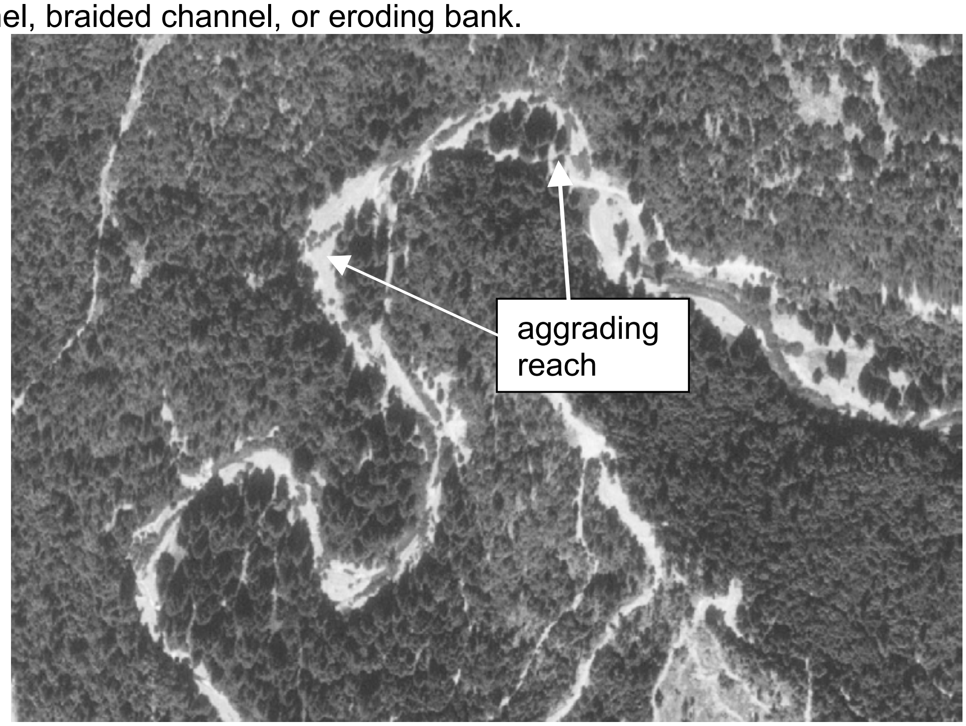
Vegetated bar (vb) – characteristic is mapped when an active channel bar is well vegetated, generally greater than 75 percent of visible bar area. This generally indicates a more stable deposit of sediment and can provide partial cover.

Vegetated lateral bar at toe of landslide

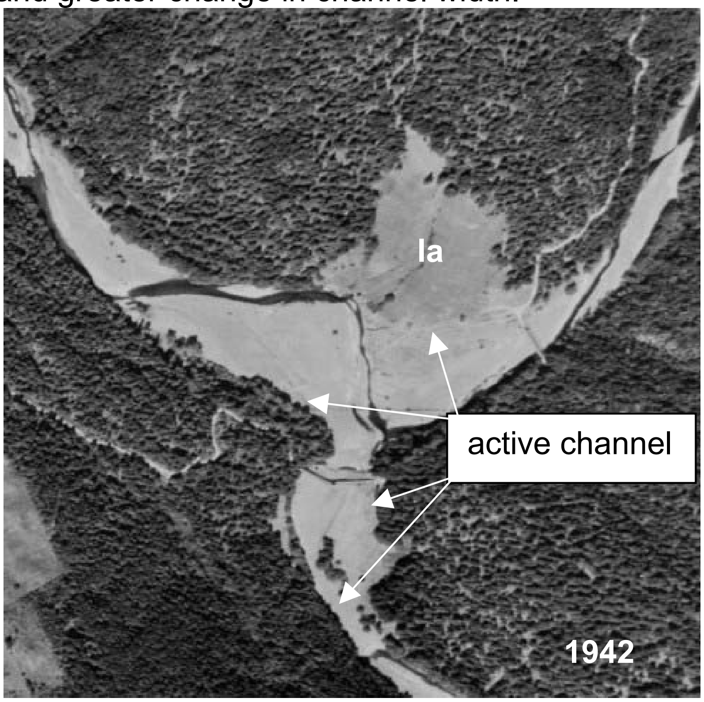
Partially vegetated bar (vp) – characteristic is mapped when the area of a bar is vegetated at less than 75 percent. This generally indicates a partially stable sediment deposit and can provide partial cover.



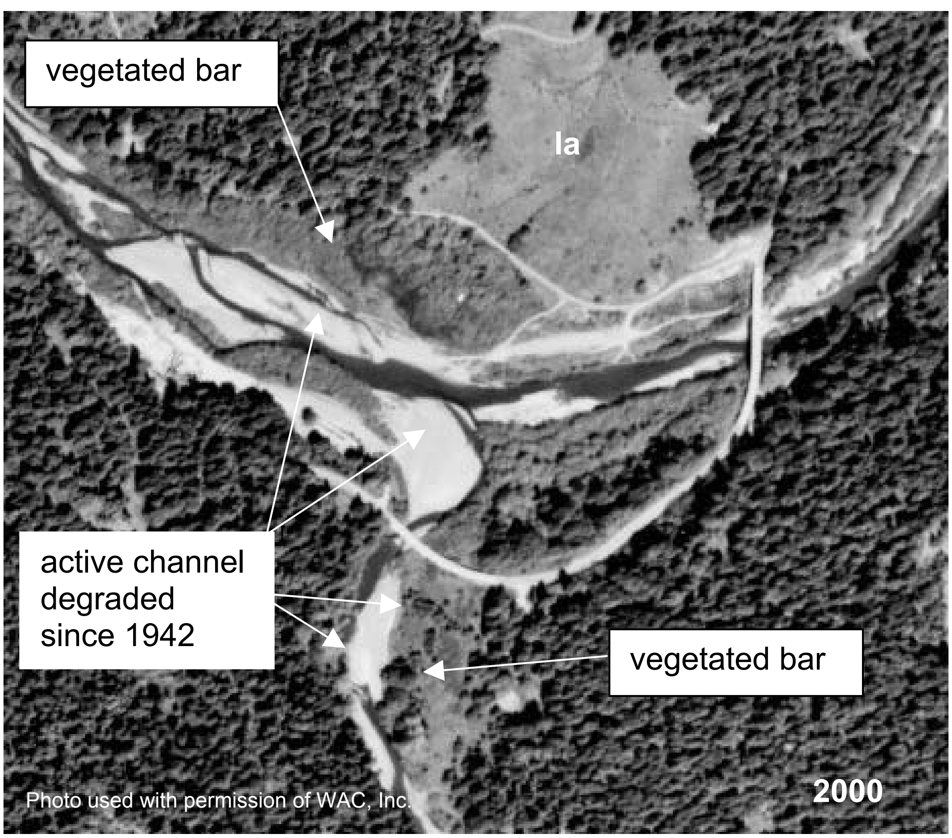
Aggrading reach (ag) – characteristic is mapped when channel deposits appear excessively wide and deep, often indicated by channel flow going into the subsurface or an anomalous widening of active channel sediment. This characteristic often associated with other attributes suggestive of a sediment source or change in channel hydraulics resulting in deposition, e.g., blocked channel, braided channel, or eroding bank.



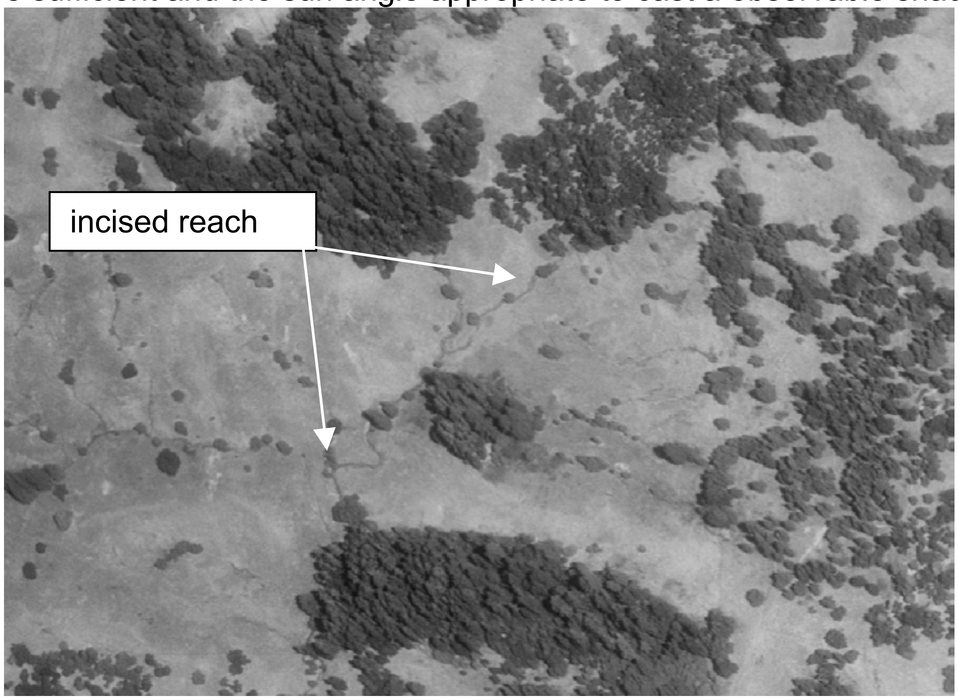
Degrading reach (dg) - characteristic is generally not easily distinguished on reconnaissance aerial photos and therefore difficult to map from aerial photos at a scale of 1:24,000 without a photo time-series and field inspection. This characteristic is distinguish from incised channels in its greater longitudinal extent and greater change in channel width.



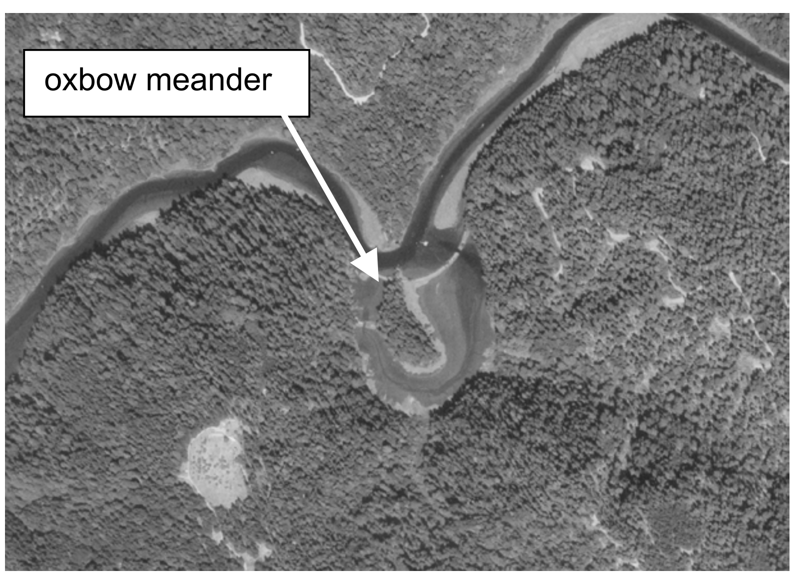
Upper photo shows channel in 1942 meandering north into toe of landslide. Lower shows channel in 2000 with vegetation established on bars south of bridge and along toe of landslide. Field observations show channel downcut several feet isolating vegetated bars.



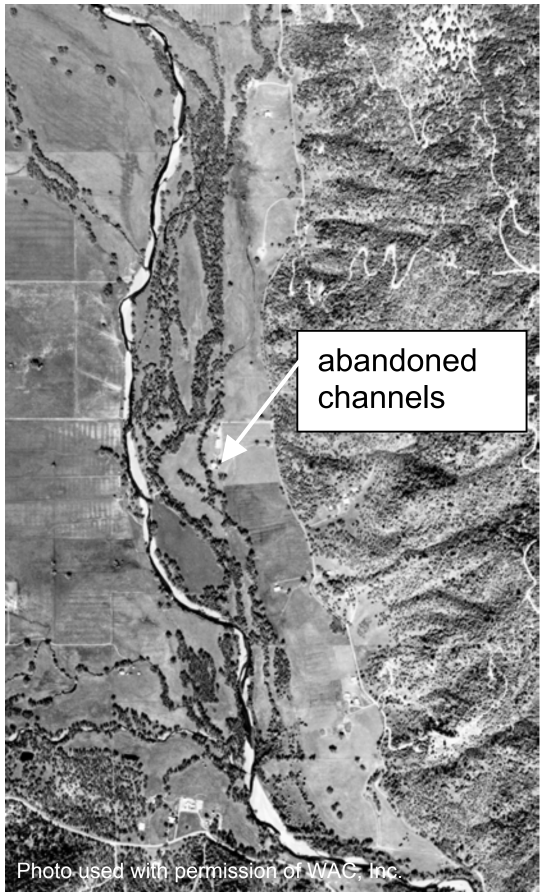
Incised reach (in) – characteristic is mapped when one or both banks of a channel have eroded vertically such that the active channel is entrenched. Because of the reconnaissance scale of aerial photos, height of the vertical bank must be sufficient and the sun angle appropriate to cast a observable shadow.



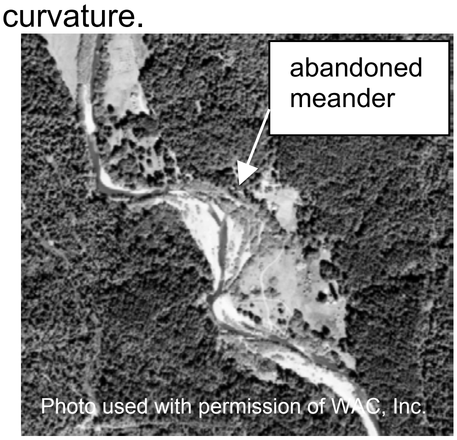
Oxbow meander (ox) – characteristic is mapped when the channel meander is cut off across the narrow piece of land that separates two sections of a tight meander and the abandoned channel partially fills with sediment leaving an isolated channel or pond. This feature is generally found in flatter gradient reaches, such as a meadow or estuary. Feature may record a significant flood event where high sediment loads filled in meander and cause a flood flow cutoff chute to become the main channel.



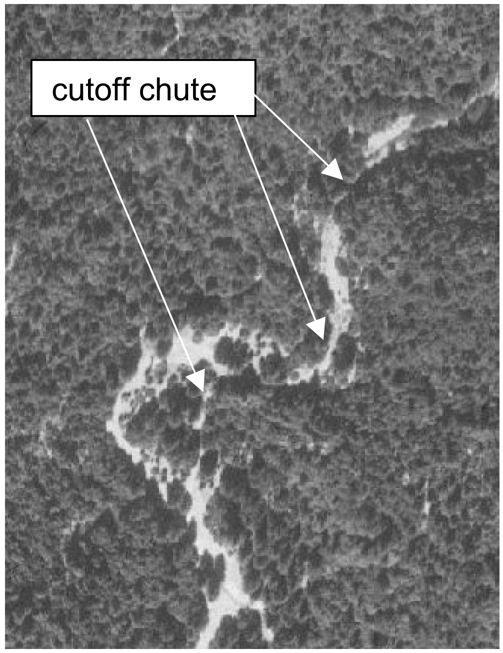
Abandoned channel (ab) – characteristic is mapped when a major channel is today inactive or abandoned as indicated by density of vegetation or height above active channel. Typically dense vegetation marks older channels that may still be in the floodplain. These channels may become active at high flood stages. Field studies are needed to determine flood stage that will inundate these channels. An abandoned channel may re-activate with avulsion of main channel during storm flows.



Abandoned meander (am) – characteristic is mapped when a meander has been cut-off or isolated from the active channel. Abandoned meanders suggest highly active channel dynamics and high bedloads. Abandoned channel is typically marked by vegetation whose density is an indication of longevity. Differs from oxbow in lesser meander curvature.

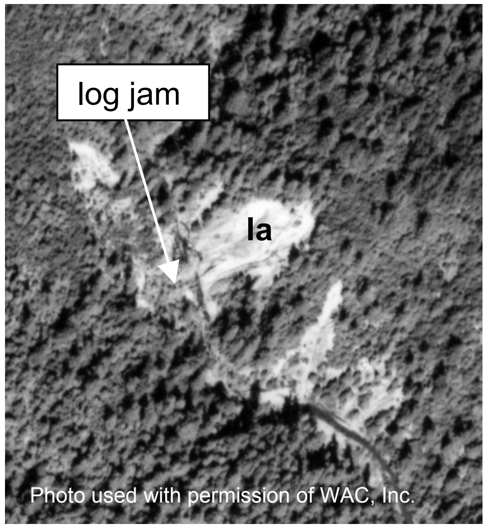


Cutoff chute (cc) – characteristic is mapped when the channel cuts across a meander bend and establishes a new side channel. Formation is typically by headward incision and indicates instability of meander. A cutoff chute may only flow during higher stages. With increased incision the meander may become isolated from the main channel and become abandoned or develop into an oxbow.

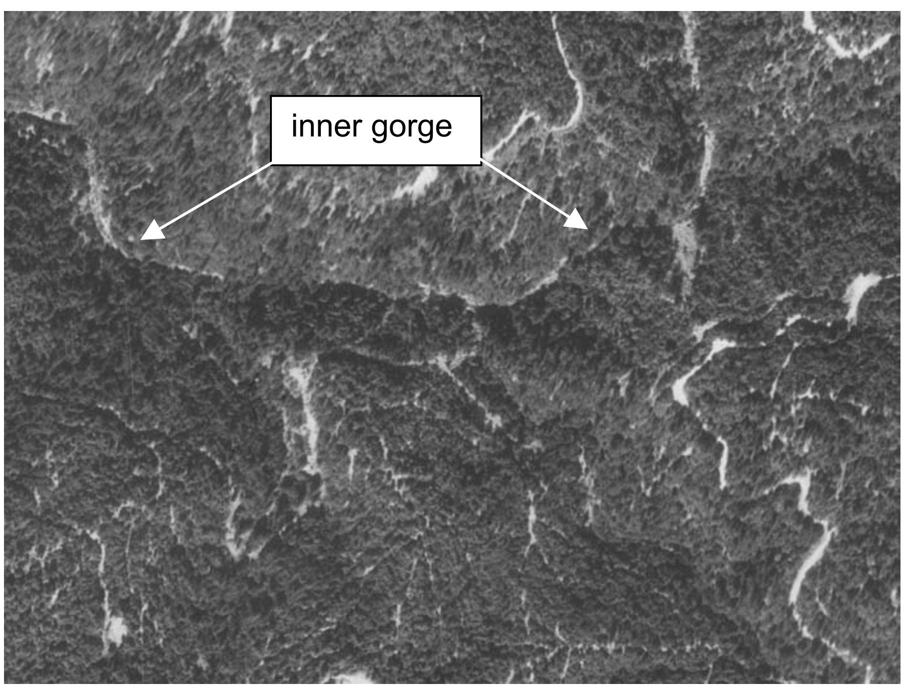


Tributary fan (tr) – characteristic is mapped when a tributary channel creates a sediment fan as it joins the main channel. Tributary fan is distinguished from a junction bar by the vertical build up of a fan-shaped deposit that has a large portion lying above the stage of normal channel flows or onto the flood plain. The tributary commonly incises into the fan sediment as it joins the main active channel.

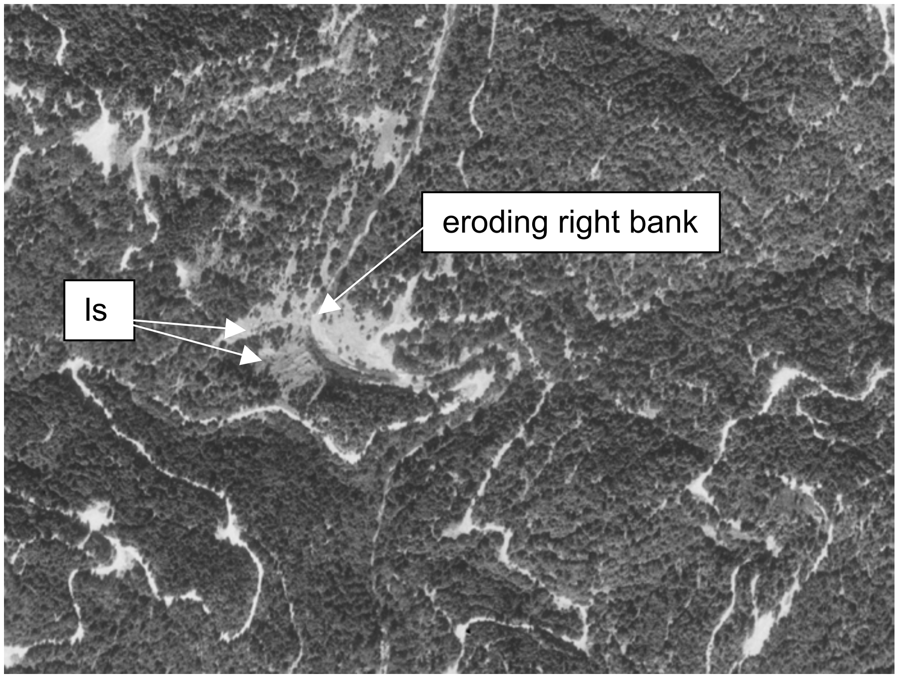
Log jam (lj) – characteristic is mapped when logs, and possibly other riparian vegetation, are observed blocking a portion of the active channel. Typically found at base of landslides that deliver sediment to the channel from wooded terrain. May form around man-made structures, particularly upstream.



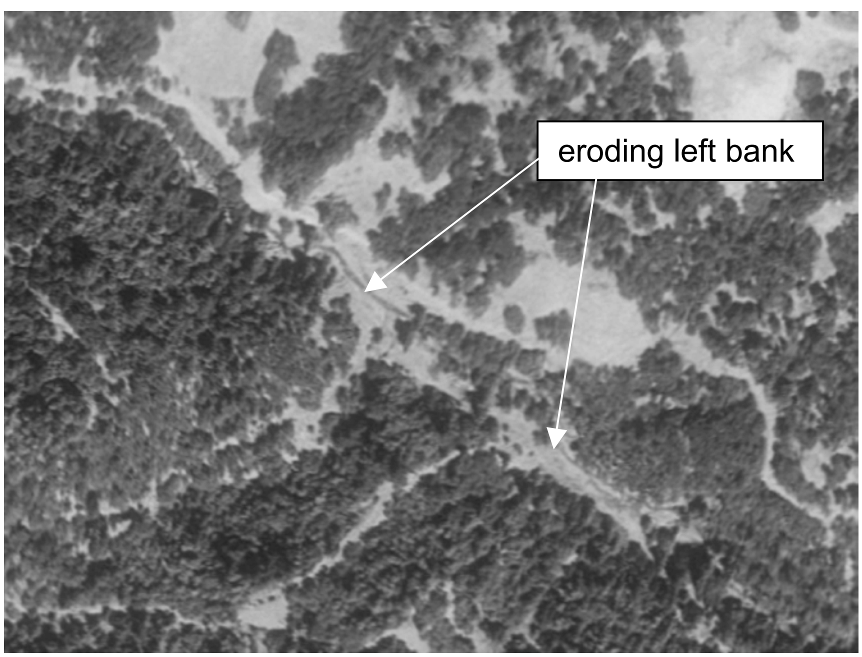
Inner gorge (ig) – characteristic is mapped where steep slopes rise from the channel and then flatten along a near linear break in slope suggesting rapid uplift and resultant channel incision. Shallow landslides are often found in the inner gorge slope. This feature is taken from landslide mapping and additional fluvial attributes area added when needed. The over-steepened slope typically has a high rate of delivery of sediment and large woody debris to the active channel.



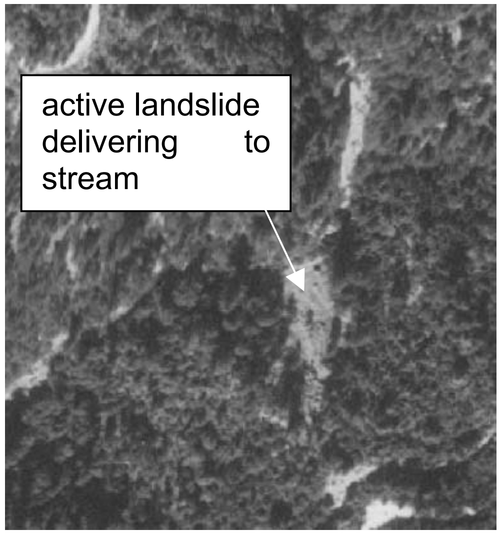
Eroding right bank (er) – characteristic is mapped when right bank of channel, when viewed facing downstream, is actively eroding. Bank erosion is often found at toe of a delivering landslide or at the outside bank of a meander.



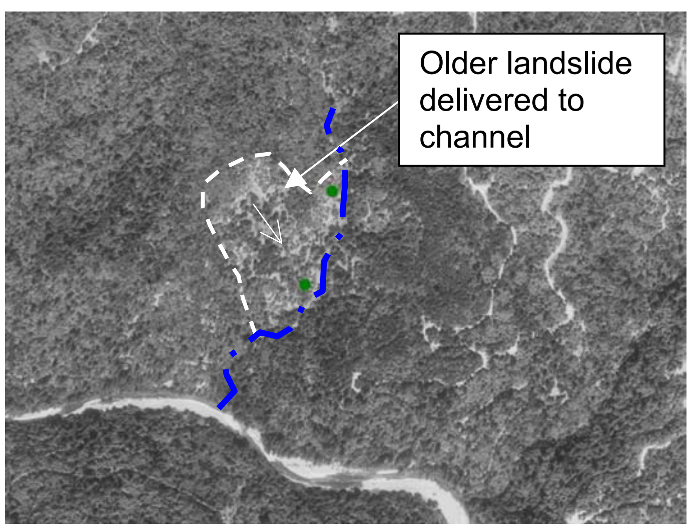
Eroding left bank (el) – characteristic is mapped when left bank of channel, when viewed facing downstream, is actively eroding. Bank erosion often found at toe of a delivering landslide or at the outside bank of a meander.



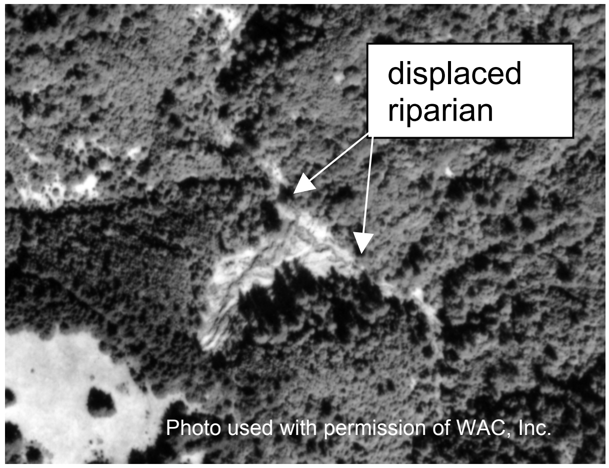
Active landslide deposit (la) – characteristic mapped is typically a smaller, poorly vegetated, landslide that appears to deliver sediment to the channel. These features are mapped and provided to the landslide mapping staff for their review and entry into the landslide mapping GIS layers. These slides are mapped by fluvial mapping staff because their closer scrutiny of near channel slopes aids in finding the smaller landslides and provides a quality control check to the delivering shallow landslide database.



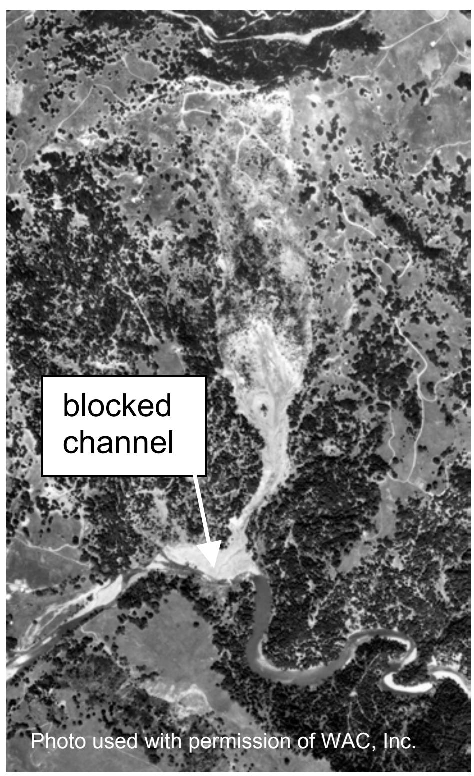
Older landslide deposit (lo) – characteristic mapped is typically a small, moderately- to well-vegetated, landslide that appears to have delivered sediment to the channel. These features are mapped and provided to the landslide mapping staff for their review and entry into the landslide mapping GIS layers. These slides are mapped by fluvial mapping staff because their closer scrutiny of near channel slopes aids in finding the smaller landslides and provides a quality control check to the delivering landslide database.



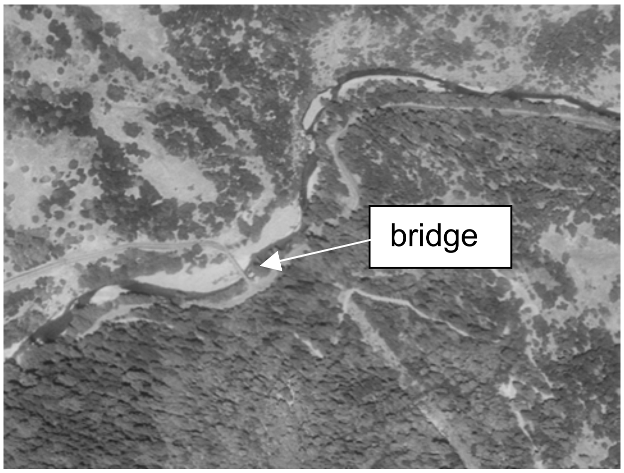
Displaced riparian (dr) – characteristic is mapped when sediment, typically from a landslide, disrupts or displaces riparian vegetation along the channel. Typically this attribute is noted with other channel characteristics, such as active landslide deposit, blocked channel or wide channel.

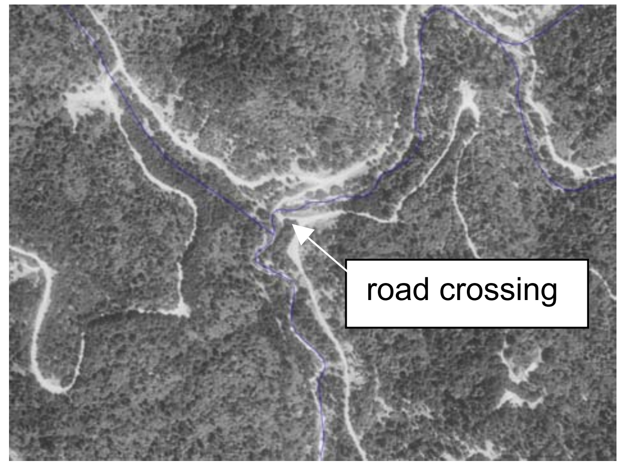


Blocked channel (bc) – characteristic is mapped when landslide delivers sufficient sediment to the channel to back up or significantly divert the flow of water. Channel flow typically disappears or becomes significantly reduced over the blocked reach. Channel often incises to re-establish an active channel.



Man-made structure (ms) – characteristic is mapped when a man-made structure is observed. Structures can influence stream flows and/or stream sedimentation. Typically this feature is identified when sediment deposits are noticed near a bridge, culvert or road crossing suggesting that the structure influences channel hydraulics.





Gully – characteristic must be seen on aerial photo and therefore can only mapped in partially vegetated or grassland areas. Feature is sufficiently long and deep that it casts a discernable shadow on imagery. A gully often is found in proximity to a landslide or road. Feature is mapped as a line and placed on a separate layer from other fluvial characteristics because it is outside the 1:24,000 blue line drainage network. A gully would be attributed as entrenched if it were part of the 1:24,000 stream network.